Prepared for:
BASF
Florham Park, NJ

Prepared by:
AECOM
Grand Rapids, MI
60439582
October 19, 2016

Corrective Measures Implementation Work Plan Addendum – Lake Macatawa Sediment Removal

Former BASF Corporation
Howard Avenue Facility
Holland, Michigan

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John A. Bleiler

Prepared By John Bleiler

Randy Ellis

Reviewed By Randy Ellis

Michael Gardner

Reviewed by Mike Gardner, PE

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List of Acronyms

AECOM	AECOM Technology Services
BASF	BASF Corporation
BAZ	Bio-Active Zone
BERA	Baseline Ecological Risk Assessment
CKD	Cement Kiln Dust
CMIWP	Correct Measures Implementation Work Plan
COPCs	Constituents of Potential Concern
CY	Cubic Yard
DEQ	Department of Environmental Quality
DIP	Ductile Iron Pipe
FD/RC	Final Decision and Response to Comments
GPS	Global Positioning System
HDPE	High Density Polyethylene
mg/Kg	milligram per kilogram
ML/OL	Soft Silt and Organic Silt
NAD83	North American Datum of 1983
NPDES	National Pollutant Discharge Elimination System
RCP	Reinforced Concrete Pipe
RCRA	resource Conservation and Recovery Act
RTK	Real Time Kinematic
SF	square feet
SM	Loose Silty Sand
SP	Poorly Graded Sand
USEPA	United States Environmental Protection Agency
USC	Unified Soil Classification

1.0 Introduction

AECOM Technology Services (AECOM) has prepared this Correct Measures Implementation Work Plan (CMIWP) Addendum on behalf of BASF Corporation (BASF). The CMIWP describes the design, permitting, and construction sequence for a focused sediment removal action in Lake Macatawa adjacent to the former BASF site, in Holland, Michigan (Site).

In a January 27, 2016 communication, the U. S. Environmental Protection Agency (US EPA) Region 5 requested a Corrective Measures Work Plan for a focused sediment removal action as recommended in AECOM's November 2015 Lake Macatawa Sediment Baseline Ecological Risk Assessment (BERA). The BERA identified potential ecological risks associated with benthic receptor exposures to elevated barium concentrations in surface sediments. The sediment removal action described in this CMIWP will address these impacts through focused removal of sediments to ensure that the remaining barium concentrations in sediment are protective of benthic receptors.

A Draft CMIWP was provided to the US EPA Region 5 on April 30, 2016 and US EPA comments on this document were received on July 29, 2016. This document has been revised in response to the agency comments and a Response to Comments document has been submitted to the US EPA concurrently with this revised CMIWP.

1.1 Site Setting and Background

The former BASF facility is located on the northern shore of the eastern basin of Lake Macatawa within the Lake Macatawa Watershed. Figure 1-1 depicts the Site and Lake Macatawa, a five mile long freshwater body that forms at the junction of the Macatawa River with Lake Michigan. BASF operated the facility from 1979 until May 1, 1996 when it was sold to Flint Ink Corporation.

The portion of the Site that abuts Lake Macatawa is separated from the former BASF facility by Howard Avenue. The Facility's water treatment plant was formerly located in this area and has since been decommissioned. This area is currently landscaped with lawn, trees, an asphalt driveway, and a gravel parking area. The area is fenced and houses a 42 foot (ft) by 30 ft single story steel frame building located along Howard Avenue. Residential properties and condominiums are located to the east and west. The abutting properties directly on the shoreline have docks and finger piers extending into the lake.

Storm water and treated wastewater from the decommissioned plant were historically discharged to Lake Macatawa under a National Pollutant Discharge Elimination System (NPDES) permitted outfall located approximately 300 feet southeast of the shoreline. Flint Ink stopped discharging treated wastewater to the NPDES outfall in spring 2008 and currently only storm water is being conveyed via the outfall. The NPDES outfall pipe is shown on Figure 1-1.

The BASF Holland Site, including Lake Macatawa, has been under investigation as part of a Resource Conservation and Recovery Act (RCRA) Corrective Action program for much of the past decade. In August 2009, USEPA issued a Final Decision and Response to Comments (FD/RC) for the selection of Remedial Alternative for BASF Facility, Holland, Michigan (USEPA, 2009) requiring BASF to draft a work plan identifying an approach to assess sediment quality in Lake Macatawa. The USEPA Final Decision indicated that BASF should develop a scope of work "to delineate the nature and extent of sediment contamination and to conduct site specific toxicity testing to determine whether potential risks exist to aquatic habitat and biota." BASF submitted a Sediment Sampling Work Plan to USEPA Region 5 in April 2010, followed by a revised work plan in September 2010 (AECOM, 2010). The revised work plan was approved by USEPA on October 19, 2010. Subsequent to Work Plan approval, surficial and sub-surficial sediment samples were collected from Lake Macatawa adjacent to the Site (Figure 1-2) and at nearby reference areas in July 2011. The results of this program were reported in the *Sediment Sampling* Report (AECOM, 2012) and further analyzed in the January 2013 *Proposed No Action Remedy Addendum* (AECOM, 2013) to the Sediment Sampling Report.

In March 2013 the USEPA Region 5 provided BASF with comments on both the September 2012 Sediment Sampling Report and the January 2013 *Proposed No Action Remedy* Addendum to the Sediment Sampling Report. In their March 2013 comment letter, the USEPA suggested that the *No Action Report Addendum* did not adequately address elevated concentrations of inorganic constituents (specifically barium and copper) in sediment adjacent to the BASF Site, and that additional sampling and analysis activities focused on these two inorganic COPCs is warranted. In September 2013, BASF provided USEPA Region 5 with a Work Plan Addendum, and in October 2013 BASF provided a Food Web Model to USEPA (AECOM, 2013a, b). USEPA provided comments on these documents in January 2014, and BASF responded to these comments in July 2014. USEPA submitted additional comments in October 2014 and in April 2015, BASF provided USEPA Region 5 with responses to comments on the Sediment Sampling Report, Work Plan Addendum, and Food Web Model.

Based on the above-described ecological risk assessment documents, it was determined that there are no unacceptable ecological risks to mammals, birds, or fish. However, the potential for risks to benthic organisms from exposures to surficial sediments could not be eliminated. On June 12, 2015, USEPA provided BASF with a letter approving the response to comments and the ecological evaluations. In their June 2015 approval letter, USEPA requested that BASF integrate all components of the ecological evaluation into a comprehensive Baseline Ecological Risk Assessment (BERA) report. BASF submitted the BERA report to the USEPA Region 5 on November 18, 2015. USEPA comments on the BERA were received on March 11, 2016, and the BERA report has been revised and finalized in response to these comments (and is being submitted to USEPA Region 5 concurrently with this work plan).

The BERA evaluated potential risks to the benthic community based on laboratory toxicity test results. The results of the benthic toxicity testing program indicate that there is a potential for benthic toxicity associated with exposure to barium in surficial sediments. Multiple lines of evidence were reviewed in the BERA in order to develop barium effects concentrations that are protective of benthic ecological receptors. For three of the four toxicological endpoints evaluated in the risk assessment (midge survival, amphipod survival, amphipod growth), the risk assessment determined that a barium concentration of approximately 6,400 milligrams per kilogram (mg/Kg) is protective of benthic receptors.

On July 29, 2016 the US EPA approved the BERA and the use of a risk-based sediment remediation goal of 6,400 mg/Kg for barium in Lake Macatawa sediments.

1.2 Remedial Action Summary

The focused sediment removal action presented in this CMIWP includes the following elements:

- Installation of temporary upland site facilities including fencing, access roads, contained stockpile and staging areas, and erosion and sediment controls
- Installation of turbidity curtains around the dredge areas
- Implementation of turbidity and ambient air monitoring
- Mechanical dredging of surficial sediments (approximately 0 to 2 feet deep) and transfer of dredge material to the upland staging area
- Sediment dewatering via gravity drainage and/or use of drying agents and treatment and discharge of any water generated
- Loading, transportation, and off-site disposal of the dewatered dredge material
- Placement of a sand cover over the dredged area
- Removal of temporary facilities and demobilization

Details for the design, permitting and construction of these elements are provided below.

1.3 CMIWP Objectives

Based on the results of the BERA, eliminating potential benthic receptor exposures to surficial sediments containing barium concentrations in excess of 6,400 mg/Kg has been established as the primary remedial action objective for this CMIWP Addendum. A secondary objective has been established to include management of copper-containing sub-surficial sediments at several sampling locations in Lake Macatawa. Management of barium and copper-containing sediments will appreciably reduce the potential for ecological risks at this Site under current and future foreseeable conditions.

This CMIWP identifies primary design considerations, establishes permit requirements, and presents a conceptual construction sequence for the focused sediment removal action. Two primary objectives of this document are (1) to gain US EPA concurrence with the scope of the response action outlined in this Work Plan, and (2) to demonstrate that the sediment removal can be implemented in a manner that is protective of the public health and the environment. The CMIWP provides a clearly established basis for preparation of the detailed design and bid documents needed to permit and implement the focused sediment removal action.

2.0 Design Considerations

This section describes the sediment removal components and presents the considerations and rationale used to design the specific elements of the remedial response action.

2.1 Design Objectives

The BERA evaluated risk to benthic receptors for four toxicological endpoints (midge survival, amphipod survival, amphipod growth, and midge growth). The results determined that a barium concentration of approximately 6,400 mg/Kg is protective of the majority of benthic receptors.

Therefore, the primary objective of this focused sediment removal is to ensure that barium concentrations in surficial sediments within the bioactive zone (BAZ) are below 6,400 mg/kg (the BAZ at this site has conservatively been assumed to be approximately 6 inches in depth). As discussed above, a secondary objective – management of sub-surficial sediments containing copper at several sampling locations – has also been established for the Lake Macatawa site. These objectives will be achieved through a combination of sediment removal via dredging and installation of a sand cover in the dredged areas.

2.2 Dredge Limits and Volumes

The proposed dredge limits were established by evaluating barium concentrations at the samples locations shown in Figure 2-1. Sample depth intervals of 0 to 0.5 foot, 0.5 to 2 foot, 2 to 4, and 4 to 6 foot depth were evaluated separately. Barium concentrations in excess of 6,400 mg/Kg were observed at the following sample locations:

- From 0 to 0.5 feet – sampling locations SD-25, SD-30, SD-31, and SD-53
- From 0.5 to 2 feet – sampling locations SD -30, SD-31, and SD-34
- From 2 to 6 feet - no samples were characterized by barium concentrations above 6,400 mg/Kg

Thiessen Polygons of the areas with barium concentration in excess of 6,400 mg/Kg were drawn from the sample data at each depth interval. The results of this analysis are shown in Figure 2-2. The observed barium concentrations at each sample location are provided in Appendix A. This analysis indicates that, in order to achieve the barium remedial action objective, dredging from 0 to 2 feet depth is required over 28,760 square feet (SF); an additional 18,480 SF will need to be dredged from 0 to 0.5 feet depth.

In order to manage copper concentrations in the sub-surface, additional dredging at two sampling locations will occur:

- From 2 to 4 feet – sampling locations SD-30 and SD-31

Assuming a 0.5 foot over dredge in all areas and sloughing at the dredge area perimeter, approximately 5,100 cubic yards (CY) of dredging will be required to manage barium and copper containing sediments at Lake Macatawa (Figure 2-3)

Dredge Area	Area (SF)	Dredge Vol (CY)
0 – 0.5 Ft (outside 2ft footprints) (SD25 and SD53)	18,476	800
0 – 2.0 Ft (SD30, SD31, SD34)	28,766	2,800
2.0 – 4.0 Ft (SD30, SD31)	14,836	1,500
Total	**62,078**	**5,100**

An analysis of all barium sediment data collected by BASF was conducted to evaluate whether or not there are sufficient data surrounding the perimeter and bottom of the dredge area to ensure that all sediment containing barium above the cleanup level will be removed. This evaluation was conducted using thessian polygon analysis, as presented in Figure 2-4. More than 100 barium samples were collected as part of the remedial investigation and risk assessment program. These locations included 37 surficial (0 to 0.5 ft) and approximately 63 sub-surficial samples (0.5 to 6 feet). An evaluation of perimeter samples surrounding the proposed areas, as well as sub-surficial samples below the dredge areas, indicates that there are no samples surrounding or beneath to dredged area containing barium concentrations in excess of the 6,400 mg/Kg remedial goal). Based on this analysis, it was determined that there are sufficient data to determine with a high degree of certainty that the area to be removed is well-defined ant that post-excavation or confirmation sampling is not required at this Site.

2.3 Physical Setting

2.3.1 Upland Area

The upland area adjacent to the Lake will be used to offload, stage, dewater, and load out the dredged sediment. Along Howard Avenue the upland area is fairly level at elevation 603± feet above the North American Vertical Datum of 1988 (NAVD88). From the central portion of the upland area to the shoreline, grade drops approximately 23 feet (from elevation 603 to 580 feet) over roughly 200 linear feet. The topographic information is based on CDR Pigment WWTP Modifications Drawings by Rose and Westra dated December 16, 2003. These Drawings are included in Appendix B.

2.3.2 Dredge Area

The dredge areas depicted in Figure 2-2 include two distinct areas: (1) a larger area centered around sampling location SD-30 and extending approximately 50 to 300 feet off the shoreline, and (2) a smaller area centered around sampling location SD- 53 and located approximately 500 feet off the shoreline.

A bathymetric survey of the dredge areas was conducted by Hibbard Inshore in July of 2011.. At the time of the survey the lake level was 578.6 feet above NAVD88. In the SD-30 dredge area the lake bottom elevation was between 570.5 to 573.5 feet. In the SD-53 area the lake bottom elevation was approximately 570.5 feet. Directly along the shoreline, the lake bottom elevation is approximately 575. Lake levels vary from elevation 576.80 to 582.50 based on information provided in the Rose and Westra Drawings. The resulting water depth would vary between 3 to 8 feet over the dredge area. As described below, a more current bathymetric survey is planned upon acceptance of this work plan.

2.3.3 Outfall Pipe

The Rose and Westra Drawings (Appendix B) show the modifications to the former facilities water treatment plant and NPDES outfall. According to the Drawings:

- Stormwater and treated waste water from the plant were originally discharged through a gravity 18-inch reinforced concrete pipe (RCP) that extended to a NDPES permitted discharge location 300 from the shoreline.
- A pump chamber and an 8-inch ductile iron pipe (DIP) force main was constructed approximately 10 south of the original gravity drain. This force main also discharged 300 feet from the shoreline.
- The 8-inch DIP became the primary discharge for the treated waste water.
- A portion of the 18-inch RCP gravity drain below the lake was removed.
- The upland portion of the 18-inch RCP gravity drain was left in-place and terminated at a concrete headwall on the shoreline to discharge stormwater from the former facility.

The water treatment plant was decommissioned in 2008. The 8-inch DIP force main no longer discharges water and stormwater continues to discharge through the 18-inch RCP to the headwall at the shoreline.

2.4 Sediment Properties

Logs from the sediment sample locations and results of sediment grain size results conducted during the 2012 sediment sampling are provided in Appendix C. The sediment texture across the dredge area, using Unified Soil Classification (USC) system, is predominately soft silt and organic silt (ML/OL), indicating a low energy depositional environment in the study area. Closer to the shoreline the sediment is more coarse grained consisting of loose poorly graded sand (SP), to loose silty sand (SM).

Grain size varied little within individual cores. The uniform nature of the grain size down core indicates minimal changes in lake level and shoreline position in recent past, minimal storm wave impact, overall sediment stability, and relative shore stability with respect to gravity driven slope processes.

2.5 Sediment Dredging and Handling

A detailed dredge prism will be developed during the design phase. Drawings will show horizontal position of the dredge limits relative to the North American Datum of 1983 (NAD83) and the vertical position of the dredge limits relative to NAVD88. The Drawings will allow dredging equipment controlled with a Real Time Kinematic (RTK) Global Positioning System (GPS) to accurately remove the impacted sediment with maximum over-dredge of 0.5 feet.

Based on preliminary discussions with dredging contractors and given the location and quantity of the dredge material, mechanical dredging will be the preferred removal method. The design Drawings and Specifications will include provisions (e.g., use of silt curtains and best management practices) to ensure that the mechanical dredging operations are conducted in a manner that minimizes suspension of sediment in the water column. Provisions to ensure that dredged sediment is not released outside the dredge area during transfer to and off loading at the shoreline will also be established.

The dredged sediment will be dewatered prior to loading and shipment to off-site disposal facilities. The dried sediment will need to pass the Paint Filter Test (ASTM STP993) before loading. Drying may be achieved through gravity drainage or by mixing with a dry reagent (cement kiln dust [CKD], lime, Calciment®, or other proprietary reagents). Given the sediment texture, gravity drainage alone is unlikely to yield sufficient drying. Reagent mixing may take place directly on the deck of a watertight transfer barge or in a lined mixing area in an upland support area. Any water generated during dewatering will be transferred to an off-site treatment facility or managed on site with a temporary water treatment system. Treatment at the existing groundwater treatment facility on the main Site will also be evaluated in the design phase.

A temporary haul road will be constructed across the upland area from Howard Avenue to the shoreline off-loading area. If sediment dewatering takes place in the transfer barges, then dewatered sediment could be loaded directly into trucks and shipped off-site. Alternatively, sediment may be transferred, via an off-rod truck, to a staging area located on the level portion of the upland area where it will be dewatered and loaded into trucks for off-Site disposal.

Trucks carrying sediment off-site will have beds lined with plastic sheeting bed liners. The sediment will be disposed of at a Type II Solid Waste Landfill. A decontamination area and gravel construction exit will be installed to ensure that sediment, silt, or dust is not tracked onto Howard Avenue.

2.6 Monitoring and Controls

The design documents will include requirements for turbidity control and monitoring at the perimeter of the dredge area. A single line of turbidly curtain will be deployed and maintained around the active dredge and off-loading areas. Type II curtain will be used to ensure containment of the active dredging and backfill areas under the normal currents and from the wakes caused by recreational boating. The curtain will be set in a manner that limits access to the remediation area from the boat docks belonging to the adjacent residential properties and condominiums, and that minimizes disruption to the condominium owners and their recreational boating activities.

A Turbidity Monitoring Plan will be prepared during the design. This plan will establish specific monitoring procedures and monitoring action levels to be employed during dredging and backfill activities. Buoys with real time turbidity monitors will be placed just outside the silt curtain (alternatively, turbidity will be monitored by field technicians from a small jon boat or equivalent). The design will establish turbidity action levels including warning and stop work levels. Dredging practices will be adjusted as needed to ensure that sustained exceedance of the action levels does not occur. If visible turbidity is observed outside the curtain, or if turbidity at concentrations above the monitoring plan action levels is detected at the monitors, then the following procedures may be implemented:

- Stop work;
- Inspect the monitor to ensure it is working correctly;
- Inspect the curtain to ensure it is intact and properly anchored;
- Add additional curtain; and
- Adjust the dredging or backfill rate, equipment, or operating technique.

Detailed response procedures for “warning” and “stop wok” action level exceedances will be provided in the monitoring plan.

Any upland staging areas will be bermed and lined with 40-mil high density polyethylene (HDPE) sheeting or equivalent. Ambient dust monitoring will be conducted at the perimeter of the upland area to ensure that off-site dust emissions are not generated by the work. This monitoring effort will include continuous ambient air dust monitoring during sediment unloading, stabilization, and loading within the upland area at the former Howard Avenue facility. A stand-alone Air Monitoring Plan will be included as part of the design and will include thresholds, criteria, and corrective actions, should they be needed. A spray on dust control agent or water will be applied when the dust action levels in the monitoring plan are exceeded.

2.7 Restoration and Backfill

The design Drawings will also provide the horizontal and vertical limits of backfill relative to NAD83 and NAVD88. The dredge limits will backfilled with up to 4 feet of sand (USC designation of SP, SW or SM). The sand backfill will be broadcast directly at the sediment surface (not dumped into the water column) in thin lifts (3 to 6 inches). This will minimize intermingling of sediment and backfill and ensure that a discrete sand cover is established over the dredge area. It is likely that the soft silt sediment will settle 0.5 to 1 foot under the load from the backfill. Post dredging and post backfill bathymetric surveys will be conducted to document the extent of the dredge area and the backfill cover.

2.8 Sediment Stability Analysis

In response to the US EPA comments on the Draft CMIWP, a detailed sediment stability analysis has been prepared and is included as Appendix D of this CMIWP. The sediment stability analysis evaluates the potential for sediment scour and includes evaluation of the potential effects of industrial and recreational propeller (prop) wash, wave action, and storm and current erosion under both un-remediated (current conditions) and sand-capped (future conditions) scenarios.

The sediment stability analysis demonstrates that: (1) this portion of Lake Macatawa is net depositional and that therefore deeper sediment is likely to remain undisturbed; (2) sheer stresses from natural sources in this area (current, wave action, storms, etc.) are likely to be less than the potential sheer stresses associated with recreational vessel use in this area; (3) a conservative analysis of silty material (native material under current conditions) sediment stability indicates that this material would be potentially mobilized by a recreation vessel to depths of less than 2 feet; (4) even under conservative analysis assumptions, the sheer stresses from a recreational vessel are unlikely to substantively disturb the sand backfill; (5) if any disturbance of sand backfill were to occur, the maximum sand scour hole based on analysis would be less than 7 inches, and it is likely that the disturbed sand scour hole would rapidly backfill as mobilized sand particles settle back into the hole.

Based on this analysis, it can be concluded that sub-surface sediments at this Site (below 24 inches) are unlikely to be subject to scour potential under current conditions, and that in the future, sand backfill will limit potential scour to the upper 7 inches.

2.9 Pre-Design Investigation

Completing the detailed design of the focused sediment removal action will require additional data and information including:

- Updated Bathymetric Survey – An updated survey will be conducted to ensure that the design dredge prism is consistent with the bathymetric surface at the time the dredging takes place.
- Disposal Facility Pre-characterization – Sediment samples in the dredge area will be collected and analyzed as needed to gain disposal facility acceptance. This will allow dewatered material to be loaded directly and minimize the need for staging in the upland area.
- Drying/Dewatering Study – Sediment samples will be collected and subject to dewatering studies, including gravity drainage studies and amendment studies (e.g., sediment will be

mixed with varying percentages of drying reagents to determine the optimal drying procedures).

3.0 Permitting

Completing the focused sediment removal action will require:

- A Part 301 Inland Lakes and Streams permit from the Michigan Department of Environmental Quality (DEQ)
- A Clean Water Act Section 404 or a Nationwide 38 permit from the US Army Corps of Engineers.

There also may be some co-ordination with the U.S. Coast Guard required since this area is used by commercial and recreational boats. The time to process the permits is expected to range from three to six months.

4.0 Construction Sequence

The exact construction sequence and procedures required to implement the sediment removal action will be determined by the selected Contractor (as approved by BASF) and within the framework presented in the design documents approved by USEPA. A conceptual sequence for this project, consistent with standard practice, would include:

- Mobilization
  - Obtain all state and federal environmental permits and licenses
  - Conduct a pre-dredge bathymetric survey
  - Conduct preconditions survey of the roadway
  - Preparation of Contactor submittals
  - Obtaining any local permits, approvals, or access agreements
  - Install all required upland erosion and siltation controls.
  - Mobilizing the required equipment, materials and personnel to the Site.
- Install temporary facilities;
  - Construct a temporary site haul road.
  - Construct a lined (40 mil HDPE) sediment mixing, staging and truck loading areas
  - Install a temporary portable loading dock on the shoreline which will allow shallow water access for the floating equipment and transfer of sediment with minimal disturbance to the shoreline
  - Install temporary erosion control silt fencing
  - Provide support trailers and temporary sanitary facilities and waste service.
- Install site controls
  - Conduct any background or baseline monitoring (air and water column)
  - Install turbidity curtain
  - Install turbidity monitors
  - Install fence line dust monitors
- Dredge sediment
  - Mobilize dredge barge, dredge equipment, transfer barges, and support boats to the dredge area directly from the site or from a boat ramp at another location along the Lake
  - Arrange and spud sectional barges to create a dredging platform (roughly 50 ft x 50 ft)
  - Dredge the sediment to the limits shown on the Drawings from the dredging platform using a long reach excavator with RTK GPS controls

  - Transfer the dredge material from the dredging platform to material transfer barges using a long reach material handler equipped with a hydraulic clamshell bucket. Potentially transfer sediment to a watertight dewatering barge if it is determined in the design phase that this represents the best dewatering option).
  - Transfer and off-load the sediment at the temporary portable dock.
- Dewater and dispose of the dredge material
  - Gravity dewater sediment to the extent practicable.
  - Mix in drying reagents until material passes Paint Filter Test
  - Load material into lined trucks and transport to a Type II Solid Waste Landfill for Disposal.
- Backfill the dredge areas with clean sand
  - Transfer backfill to the dredging platform
  - Place the backfill in thin lifts directly at the sediment surface to the grades shown on the Drawings.
- Conduct post dredge and post backfill bathymetric surveys
- Demobilize all equipment, materials, and temporary facilities.

The total project implementation duration is estimated at approximately 10 weeks. This includes 2 weeks for mobilization and setup, 3 weeks for dredging, 2 weeks for backfilling, and 2 weeks for demobilization. This would require a dredging processing rate of approximately 200 CY/day which is conservative under these circumstances

5.0 Corrective Measures Schedule

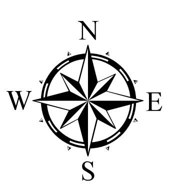
Immediately following US EPA approval of the CMIWP, BASF will begin design of the sediment removal action. Primary tasks would include:

- Pre-design Investigation (3 months)
- Preparation of remedial design documents (3 months)
- Permitting (6 months)
- Contactor procurement (2.5 months)
- Sediment removal implementation (3 months)
- Preparation, submittal, and EPA review of a report detailing completion of the sediment dredging project (2 months)

Assuming that there is some overlap in the design, procurement and permitting tasks, the sediment removal can be completed within approximately one year of USEPA approval of the CMIWP.

Figures

Map Location



BASF - Holland, Michigan Former Facility
Corrective Measures Implementation Work Plan Addendum
Lake Macatawa Sediment Removal
Site Location

0 250 500 1,000 Feet

Outfall Pipe
BASF Property Boundary

AECOM

Project # 60217278
October 2016

Figure 1-1

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Map Location

N
W E
S

BASF - Holland, Michigan Former Facility
Corrective Measures Implementation Work Plan Addendum
Lake Macatawa Sediment Removal
Sediment Sampling Locations

0 125 250 500 Feet

2011 Sediment Sampling Location
2015 Sediment Sampling Location
Outfall Pipe
BASF Property Boundary
Adjacent Offshore/Nearshore Sediment

AECOM

Project # 60217278
October 2016

Figure 1-2

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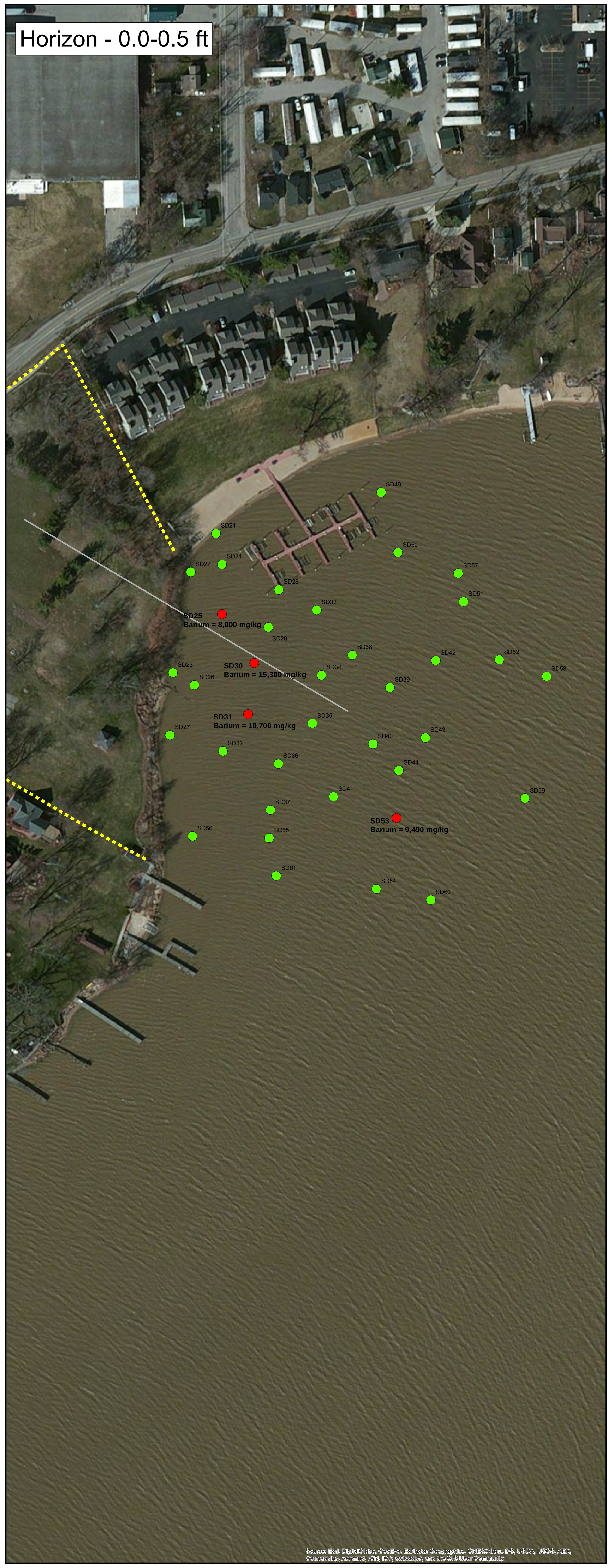

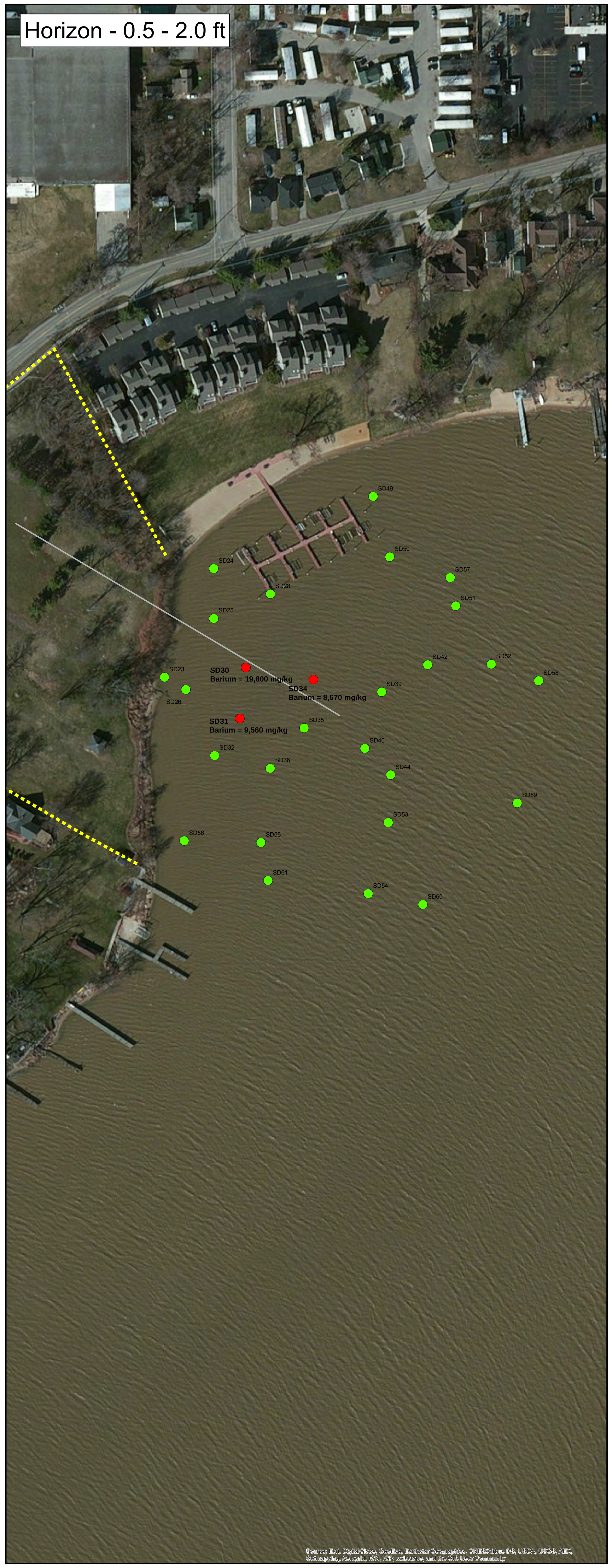

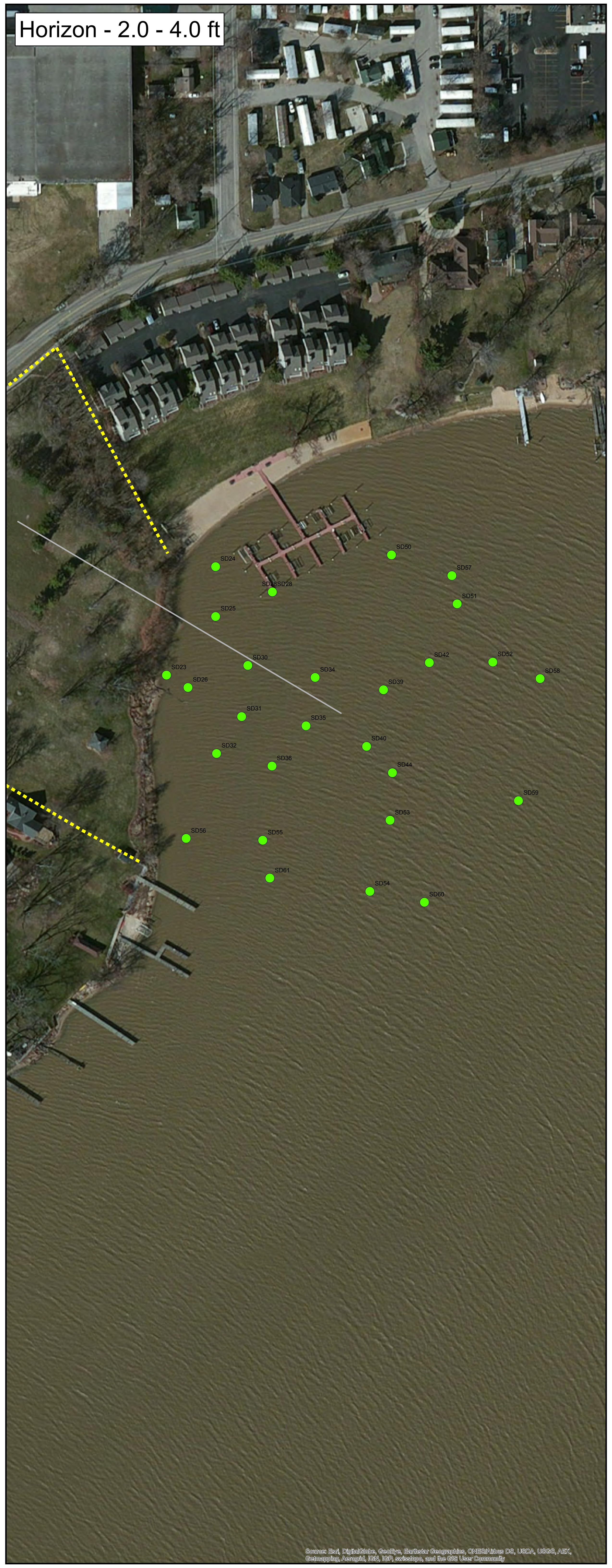

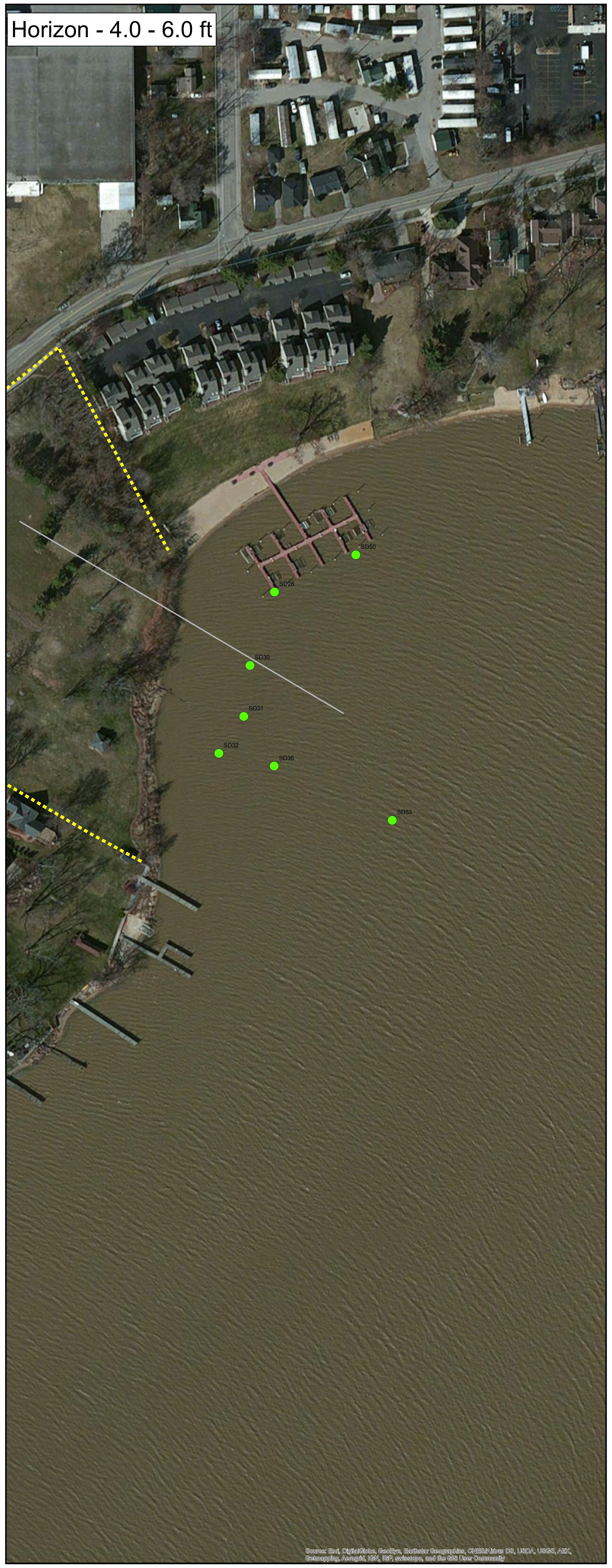

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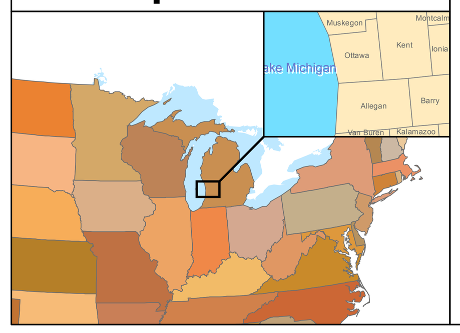
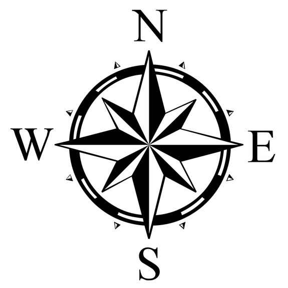




BASF - Holland, Michigan Former Facility
Corrective Measures Implementation Work Plan Addendum
Lake Macatawa Sediment Removal
Barium Concentrations (mg/kg) to 6 ft

0 250 500 1,000 Feet

Outfall Pipe
BASF Property Boundary

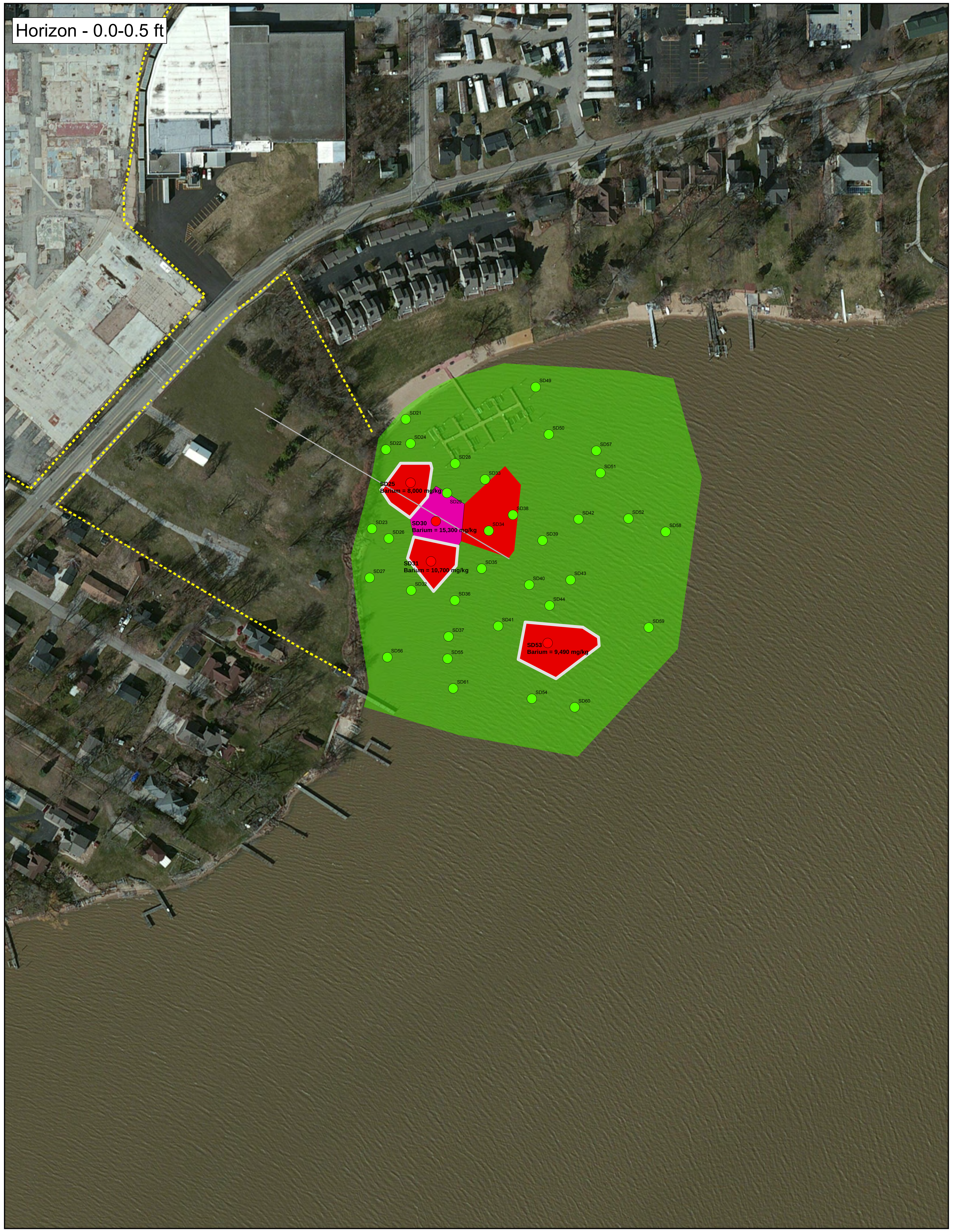
Barium (mg/kg)
<6400
>6400

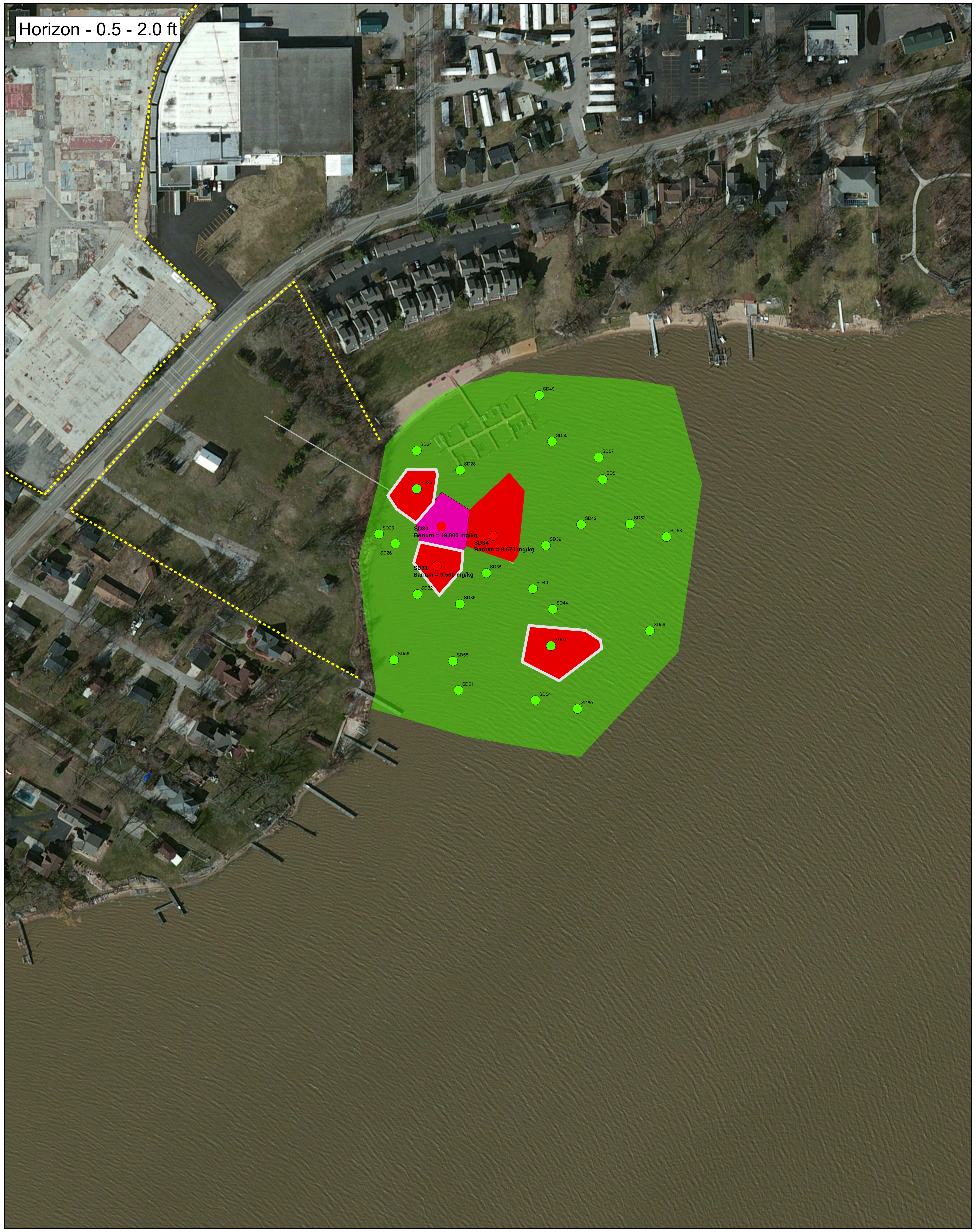
AECOM

Project # 60217278
October 2016

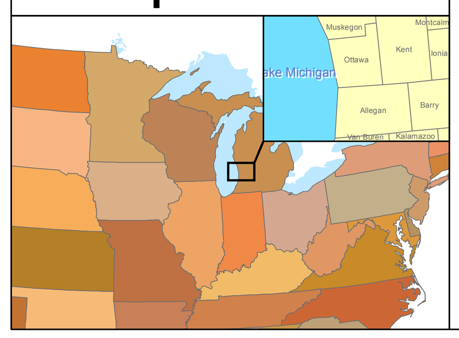
Figure 2-1

P:\Projects\Jobs\Indl_Service\Project Files\BASF-0760\Holland 0760-044\2016 Planning\2016GIS\October 2016\Barium_Points_To6Ft_2016.mxd





Map Location



N
W E
S

BASF - Holland, Michigan Former Facility
Corrective Measures Implementation Work Plan Addendum
Lake Macatawa Sediment Removal
Sediment Removal Barium Concentrations (mg/kg)

0 250 500 1,000 Feet

Outfall Pipe
BASF Property Boundary

Barium (mg/kg)	Barium (mg/kg)
<6400	<6,400
>6400	6,400 - 15,299
	>15,300

AECOM

Project # 60217278
October 2016

Figure 2-2

W:\Jobs\Indl_Service\Project Files\BASF-0760\Holland 0760-044\2016 Planning\2016GIS\October 2016\Figure_2-2_BariumPointsTo6ft.mxd

Map Location

N
W E
S

BASF - Holland, Michigan Former Facility
Corrective Measures Implementation Work Plan Addendum
Lake Macatawa Barium and Copper Removal Areas

0 125 250 500 Feet

- Outfall Pipe (Approximate Location of NPDES Outfall)
- BASF Property Boundary
- Adjacent Offshore Sediment
- Adjacent Nearshore Sediment
- 0.5 Foot Boundary
- 2.0 Foot Boundary

Barium (mg/kg)	Removal Depth
<6400	0 - 0.5'
>6400	0 - 2'
	0 - 4'

AECOM

Project # 60217278
October 2016

Figure 2-3

\\uschl1fp001\Data\Projects\Jobs\Indl_Service\Project Files\BASF-0760\Holland 0760-044\2016 Planning\2016GIS\October 2016\Figure_2-3_Dredging.mxd

Map Location

N
W E
S

BASF - Holland, Michigan Former Facility
Corrective Measures Implementation Work Plan Addendum
Lake Macatawa Sediment Removal
Barium Concentrations (mg/kg) to 6 ft

0 250 500 1,000 Feet

Outfall Pipe
BASF Property Boundary

Barium (mg/kg)
<6400
>6400

Removal Depth
0 - 0.5'
0 - 2'
0 - 4'

Sample ID: SD34
Barium Concentration (mg/Kg): 8670

AECOM

Project # 60217278
October 2016

Figure 2-4

\\uschi1fp001\Data\Projects\Jobs\Indl_Service\Project Files\BASF-0760\Holland 0760-044\2016 Planning\2016GIS\October 2016\Figure 2-4.mxd

Appendix A

Barium Concentrations

UPDATED 04/15/16

Surface (0.0 - 0.5)				
Location	Depth	Barium (mg/kg)	Year	SqFt
SD21	0 - 0.5	7.80	2011	6,821.36
SD22	0 - 0.5	10.00	2011	4,481.39
SD27	0 - 0.5	14.30	2011	8,374.53
SD49	0 - 0.5	24.60	2011	18,570.00
SD23	0 - 0.5	29.80	2011	5,594.57
SD24	0 - 0.5	148.00	2011	4,913.99
SD57	0 - 0.5	232.00	2011	29,520.00
SD59	0 - 0.5	242.00	2011	27,110.00
SD56	0 - 0.5	246.00	2011	17,660.00
SD58	0 - 0.5	286.00	2015	25,280.00
SD52	0 - 0.5	395.00	2011	15,970.00
SD26	0 - 0.5	489.00	2011	6,134.18
SD61	0 - 0.5	647.00	2011	17,270.00
SD51	0 - 0.5	650.00	2011	9,165.29
SD60	0 - 0.5	700.00	2011	20,490.00
SD35	0 - 0.5	850.00	2011	7,785.14
SD50	0 - 0.5	961.00	2015	15,330.00
SD36	0 - 0.5	990.00	2011	6,472.51
SD28	0 - 0.5	1,020.00	2011	13,910.00
SD31	0 - 0.5	1,090.00	2011	6,366.48
SD34	0 - 0.5	1,120.00	2011	6,562.47
SD42	0 - 0.5	1,160.00	2011	11,130.00
SD55	0 - 0.5	1,180.00	2015	6,122.86
SD33	0 - 0.5	1,200.00	2011	11,660.00
SD41	0 - 0.5	1,220.00	2011	11,990.00
SD37	0 - 0.5	1,600.00	2011	6,087.27
SD39	0 - 0.5	1,960.00	2011	7,859.47
SD38	0 - 0.5	2,370.00	2011	8,761.20
SD43	0 - 0.5	2,550.00	2011	13,850.00
SD32	0 - 0.5	2,620.00	2015	8,755.95
SD54	0 - 0.5	3,080.00	2011	17,620.00
SD44	0 - 0.5	3,090.00	2011	5,169.83
SD40	0 - 0.5	3,470.00	2011	7,139.14
SD29	0 - 0.5	3,480.00	2011	5,047.77
SD25	0 - 0.5	8,000.00	2011	6,945.92
SD53	0 - 0.5	9,490.00	2015	11,530.00
SD30	0 - 0.5	15,300.00	2015	6253.34

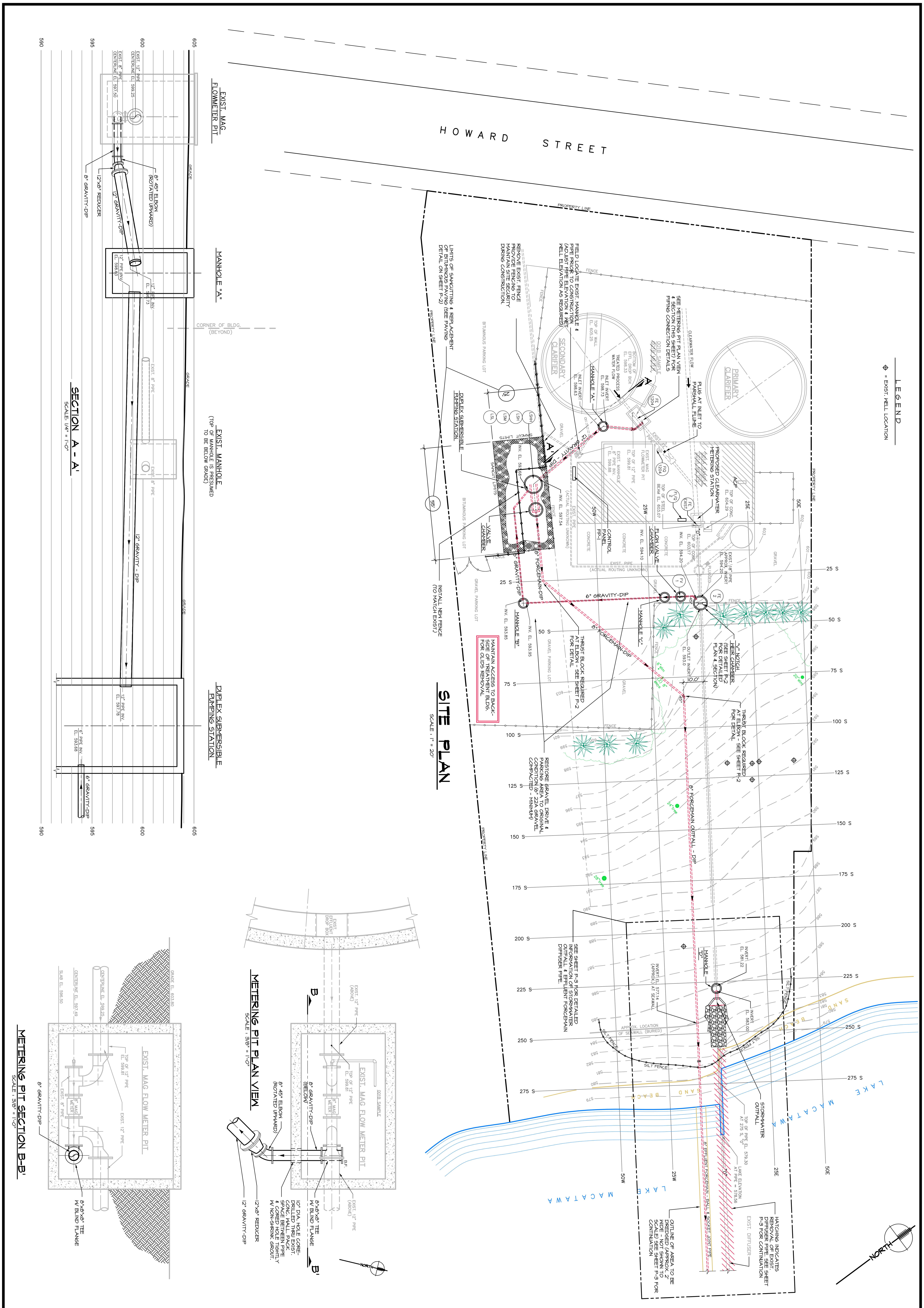
0.5 - 2.0				
Location	Depth	Barium (mg/kg)	Year	SqFt
SD49	0.5 - 2	16.80	2011	18,940.00
SD24	0.5 - 2	84.40	2011	13,510.00
SD26	0.5 - 2	105.00	2011	8,083.23
SD23	0.5 - 2	199.00	2011	8,273.98
SD39	0.5 - 2	331.00	2011	12,340.00
SD25	0.5 - 2	373.00	2011	8,874.03
SD59	0.5 - 2	394.00	2011	28,530.00
SD58	0.5 - 2	548.00	2011	25,280.00
SD52	0.5 - 2	621.00	2011	16,700.00
SD57	0.5 - 2	704.00	2011	29,520.00
SD60	0.5 - 2	707.00	2011	20,480.00
SD54	0.5 - 2	879.00	2011	19,060.00
SD50	0.5 - 2	1,110.00	2011	18,410.00
SD44	0.5 - 2	1,210.00	2011	12,460.00
SD42	0.5 - 2	1,440.00	2011	14,220.00
SD61	0.5 - 2	1,450.00	2011	17,870.00
SD51	0.5 - 2	1,520.00	2011	9,165.29
SD53	0.5 - 2	1,810.00	2015	13,940.00
SD56	0.5 - 2	2,040.00	2011	19,200.00
SD55	0.5 - 2	2,230.00	2011	11,740.00
SD35	0.5 - 2	2,430.00	2011	9,229.39
SD32	0.5 - 2	2,760.00	2015	11,650.00
SD28	0.5 - 2	3,440.00	2015	23,380.00
SD36	0.5 - 2	4,170.00	2015	10,280.00
SD40	0.5 - 2	4,720.00	2011	9,783.64
SD34	0.5 - 2	8,670.00	2011	13,930.00
SD31	0.5 - 2	9,560.00	2015	6,366.48
SD30	0.5 - 2	19,800.00	2015	8,470.59

2.0 - 4.0				
Location	Depth	Barium (mg/kg)	Year	SqFt
SD26	2 - 3	6.10	2011	8,083.23
SD24	2 - 4	10.20	2011	13,530.00
SD25	2 - 3	21.20	2011	8,874.03
SD23	2 - 4	29.50	2011	8,273.98
SD60	2 - 4	169.00	2011	20,490.00
SD56	2 - 4	188.00	2011	19,210.00
SD58	2 - 4	198.00	2011	25,280.00
SD59	2 - 4	203.00	2011	28,530.00
SD54	2 - 4	212.00	2011	19,050.00
SD52	2 - 4	241.00	2011	16,700.00
SD39	2 - 4	263.00	2011	12,340.00
SD35	2 - 4	299.00	2011	9,229.39
SD57	2 - 4	319.00	2011	29,870.00
SD42	2 - 4	331.00	2011	14,220.00
SD50	2 - 4	344.00	2015	34,460.00
SD53	2 - 4	400.00	2015	13,940.00
SD28	2 - 4	403.00	2015	25,900.00
SD44	2 - 4	649.00	2011	12,460.00
SD51	2 - 4	664.00	2011	9,165.29
SD55	2 - 4	671.00	2011	11,740.00
SD61	2 - 4	994.00	2011	17,870.00
SD40	2 - 4	1,020.00	2011	9,783.64
SD32	2 - 4	1,690.00	2015	11,650.00
SD36	2 - 4	1,810.00	2015	10,280.00
SD34	2 - 4	2,000.00	2011	13,930.00
SD31	2 - 4	3,080.00	2015	6,366.48
SD30	2 - 4	5,080.00	2015	8,470.59

Barrium > 6,400 mg/kg

Appendix B

Outfall Drawings



NO.	REVISIONS	BY	DATE
	REVISED IN ACCORDANCE WITH CONSTRUCTION RECORDS		

FILE NO: P1

DRAWN BY: KJB

DESIGN BY: BLR

DATE: 12/16/03

CDR PIGMENTS

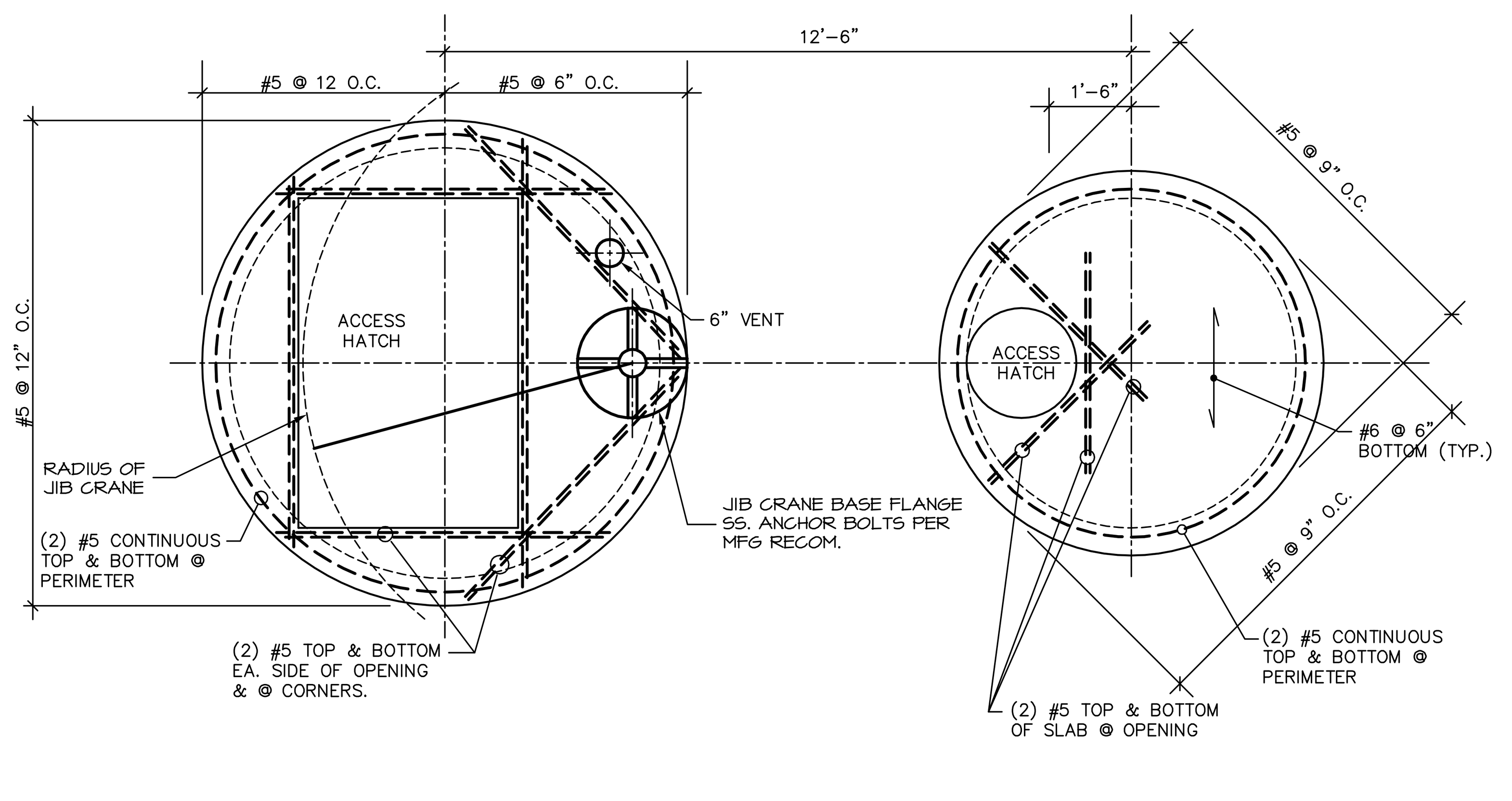
471 HOWARD AVENUE, HOLLAND, MICHIGAN

W.W.T.P. MODIFICATIONS

ROSE & WESTRA, INC.
ENVIRONMENTAL CONSULTANTS
Grand Rapids, Michigan

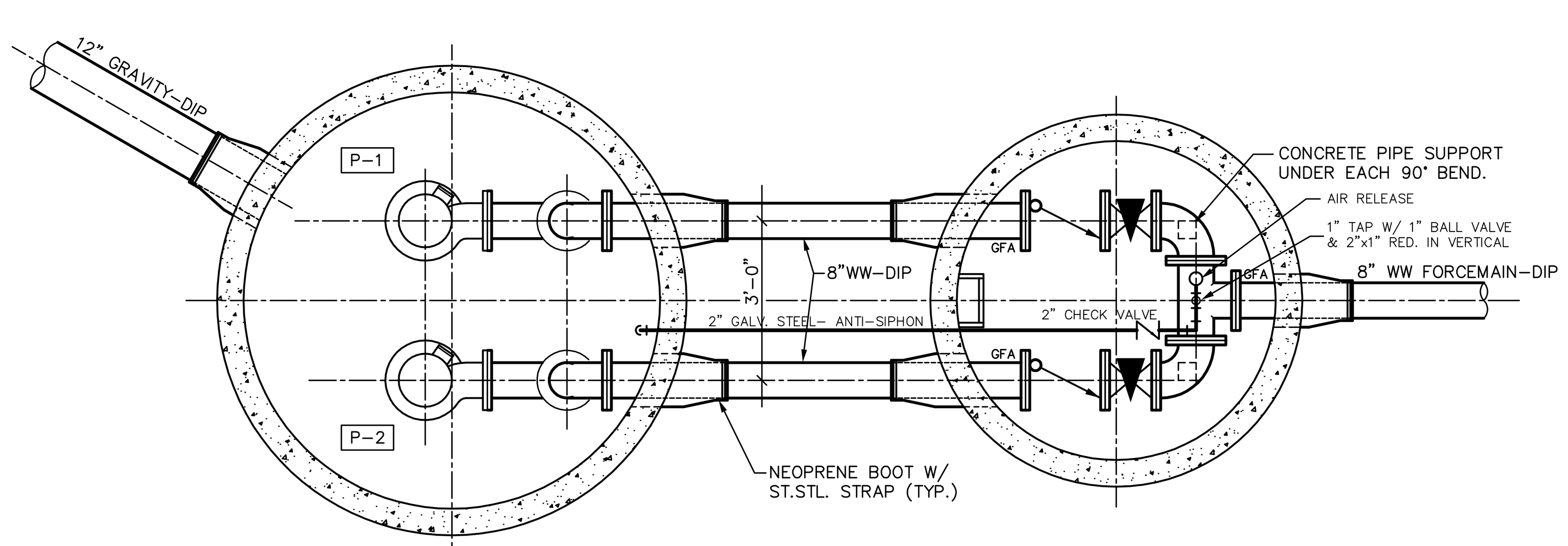
PROJECT NO. 0286013793

SHEET NO. P-1



TOP SLAB PLAN - (STRUCTURAL)

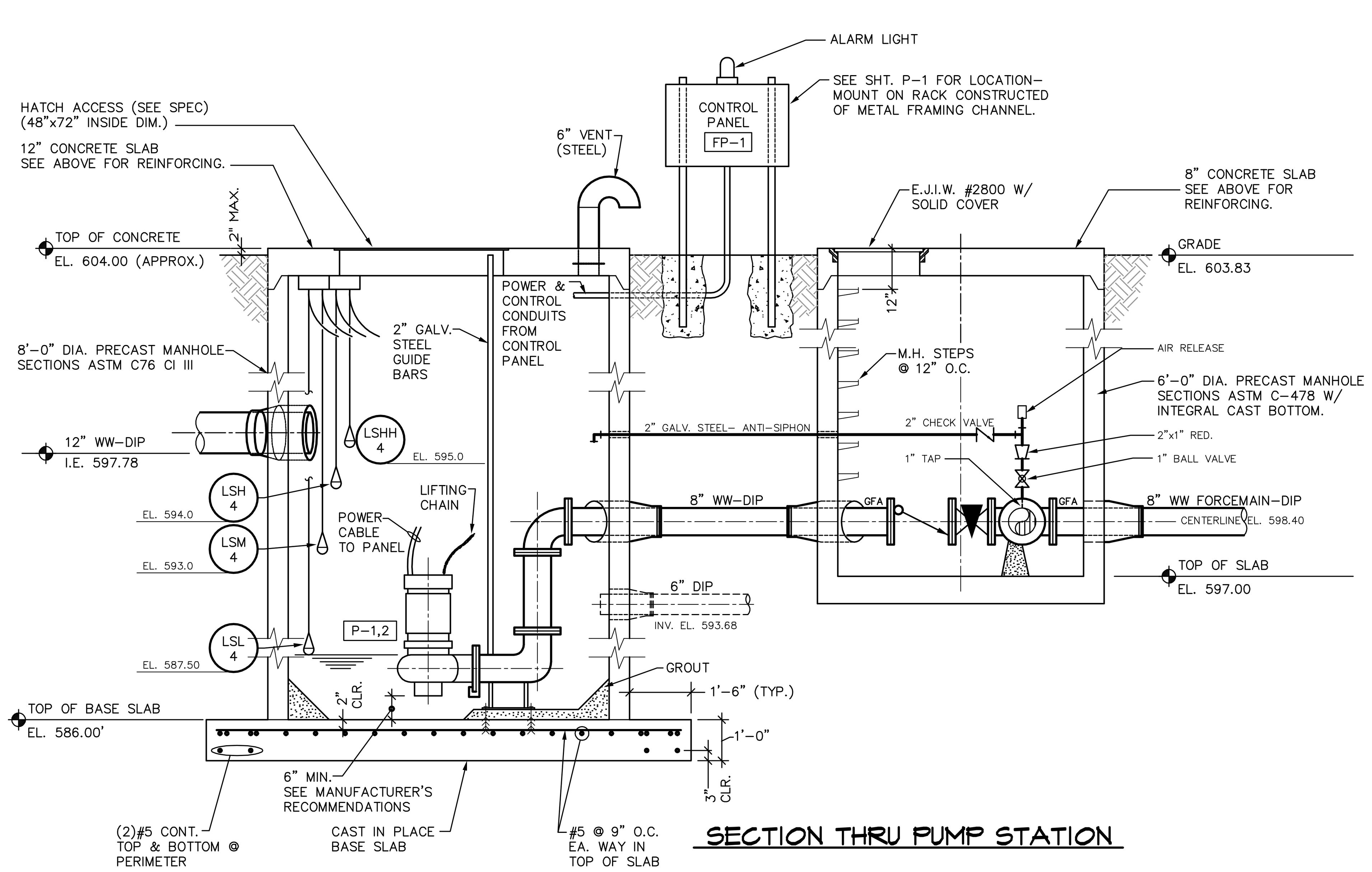
COORDINATE LAYOUT WITH PUMP MANUFACTURER



GFA = GROOVED FLANGED ADAPTOR

PUMP STATION PLAN VIEW

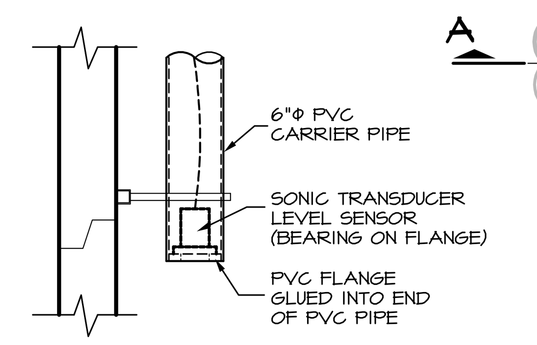
COORDINATE LAYOUT WITH PUMP MANUFACTURER



SECTION THRU PUMP STATION

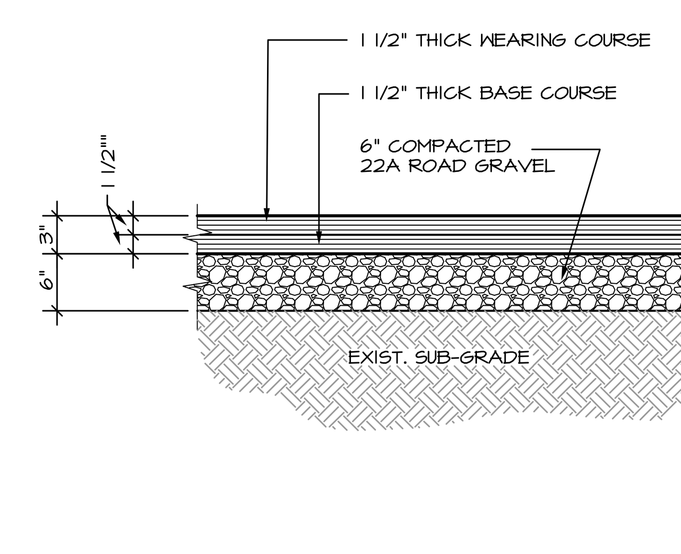
DUPLEX SUBMERSIBLE PUMPING STATION

SCALE: 3/8" = 1'-0"



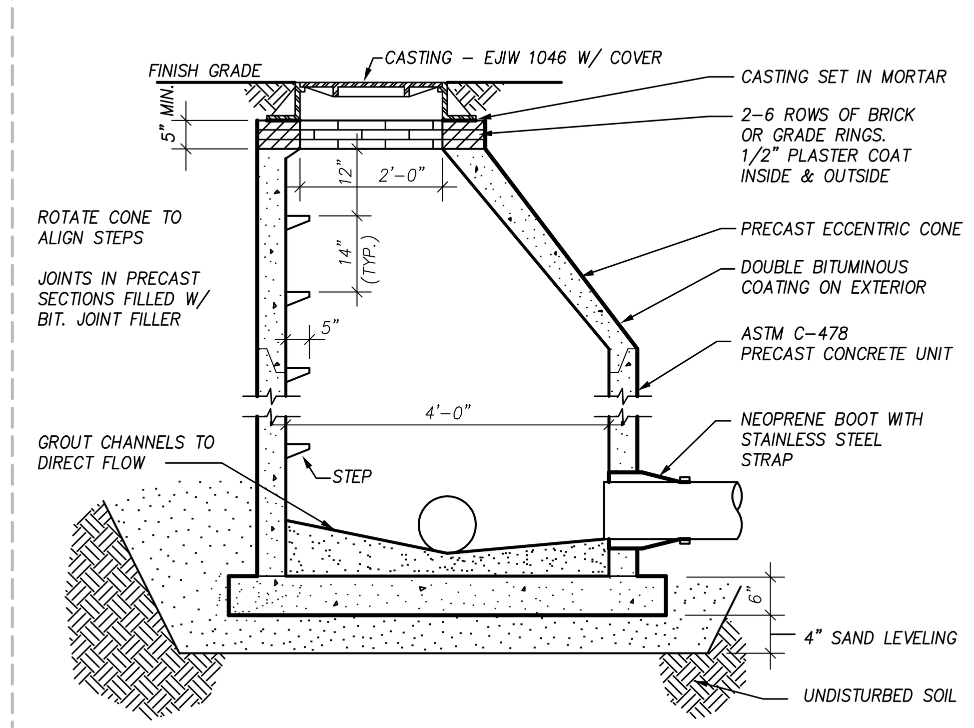
ENLARGED DETAIL OF SONIC TRANSDUCER SUPPORT

SCALE: 3/4" = 1'-0"



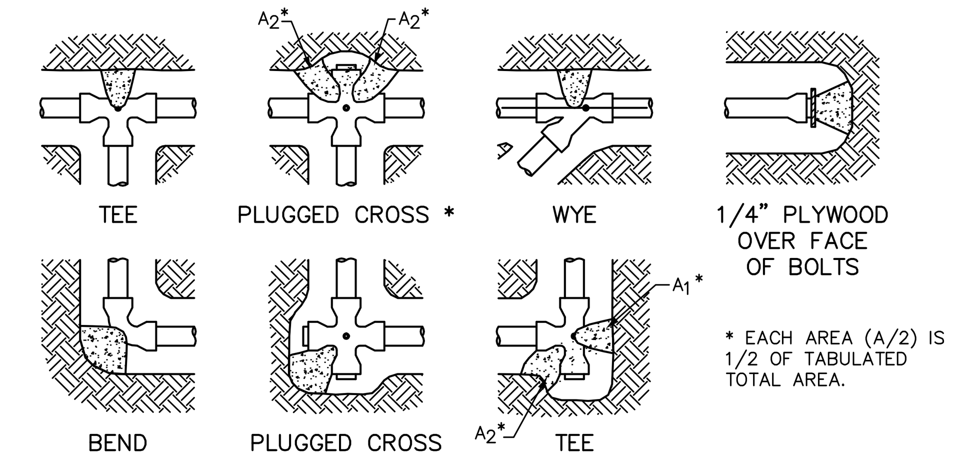
BITUMINOUS PAVING DETAIL

NO SCALE



STANDARD SANITARY MANHOLE

NO SCALE



* EACH AREA (A/2) IS 1/2 OF TABULATED TOTAL AREA.

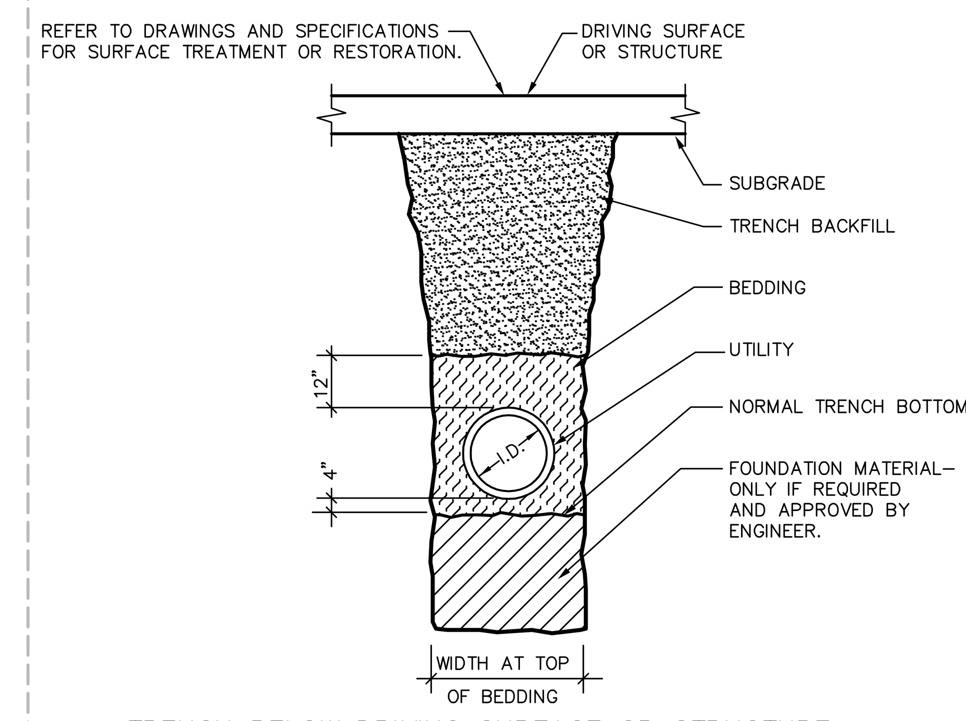
NOTES:

1. KEEP CONCRETE CLEAR OF JOINT AND JOINT ACESSORIES. PLACE BUILDING PAPER OR PLASTIC BETWEEN FITTING AND CONCREATE.
2. POUR CONCRETE THRUST BLOCK AGAINST UNDISTURBED EARTH.
3. REQUIRED VOLUMES OR BEARING AREAS AT FITTING SHALL BE AS INDICATED BELOW. ADJUSTED, IF NECESSARY, TO CONFORM TO THE TEST PRESSURE(S) AND ALLOWABLE SOIL BEARING STRESS(ES) STATED IN THE SPECIFICATIONS.
4. THRUST BLOCK VOLUMES FOR VERTICAL BENDS HAVING UPWARD RESULTANT THRUSTS ARE BASED ON TEST PRESSURE OF 150 PSIG AND THE WEIGHT OF CONCRETE = 4050 LBS./CU.YD. TO COMPUTE VOLUMES FOR DIFFERENT TEST PRESSURES, USE THE FOLLOWING EQUATION: VOLUME = (TEST PRESS./150) x (TABLE VALUE)
5. BEARING AREAS FOR HORIZONTAL BEND THRUST BLOCKS ARE BASED ON TEST PRESSURE OR 150 PSIG AND AN ALLOWABLE SOIL BEARING STRSS OF 2000 LBS./SQ.FT. TO COMPUTE BEARING AREAS FOR DIFFERENT TEST PRESSURES AND SOIL BEARING STRESSES, USE THE FOLLOWING EQUATION: BEARING AREA = (TEST PRESS./150) x (2000/SOIL BEARING STRESS) x (TABLE VALUE)
6. THRUST BLOCKS FOR VERTICAL BENDS HAVING DOWNWARD RESULTANT THRUSTS SHALL BE THE SAME AS FOR THE HORIZONTAL BENDS.
7. BEARING AREAS, VOLUMES AND SPECIAL BLOCKING DETAILS SHOWN ON DRAWINGS TAKE PRECEDENCE OVER THIS STANDARD.
8. BEARING AREA OF THRUST BLOCK SHALL NOT BE LESS THAN 1.0 SQ.FT.
9. VERTICAL BENDS THAT REQUIRE A THRUST BLOCK VOLUME EXCEEDING 5 CUBIC YARDS REQUIRE SPECIAL BLOCKING DETAILS. SEE DRAWINGS.
10. CONCRETE SHALL BE 3000 PSI.

BEARING AREA OF THRUST BLOCKS IN SQ. FT. (HORIZONTAL BENDS)								VOLUME OF THRUST BLOCK IN CUBIC YARDS (VERTICAL BENDS)			
FITTING SIZE	TEE, WYE PLUG, OR CAP	90° BEND PLUGGED CROSS	TEE PLUGGED RUN		BEND ANGLE			FITTING SIZE	BEND ANGLE		
			A_1	A_2	45°	22.5°	11.25"		45°	22.5°	11.25"
4" & SMALLER	1.0	1.4	1.0	1.4	1.0	1.0	1.0	4" & SMALLER	1.1	0.4	0.2
6"	2.1	3.0	2.1	3.0	1.6	1.0	1.0	6"	2.7	1.0	0.4
8"	3.8	5.3	3.8	5.3	2.9	1.5	1.0	8"	4.0	1.5	0.6
10"	5.9	8.4	5.9	8.4	4.6	2.4	1.2	10"	6.0	2.3	0.9
12"	8.5	12.0	8.5	12.0	6.6	3.4	1.7	12"	8.5	3.2	1.3

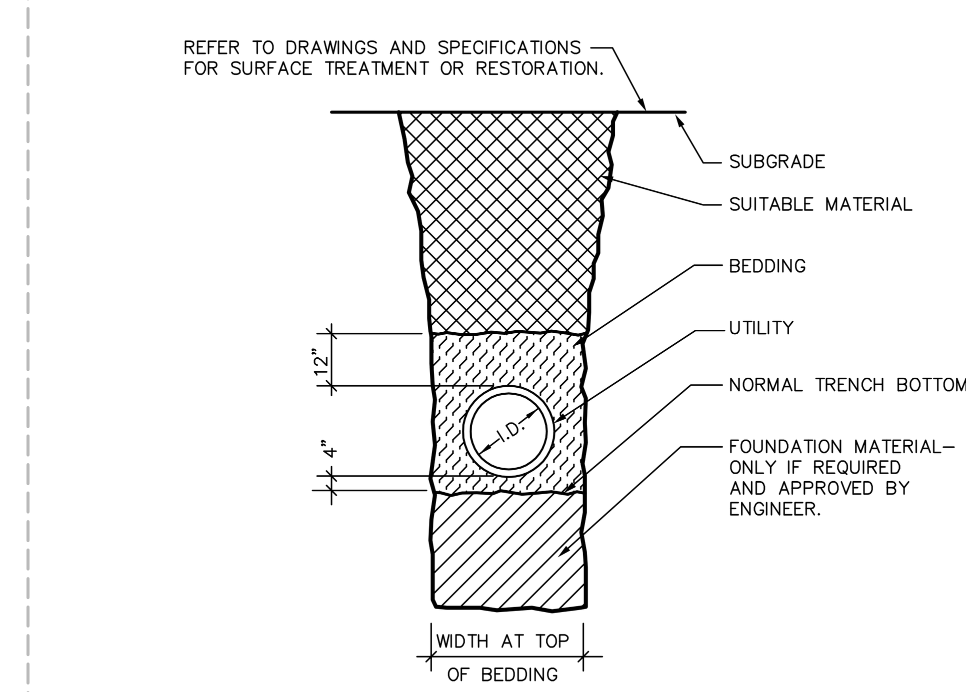
THRUST BLOCK DETAIL C03

NO SCALE



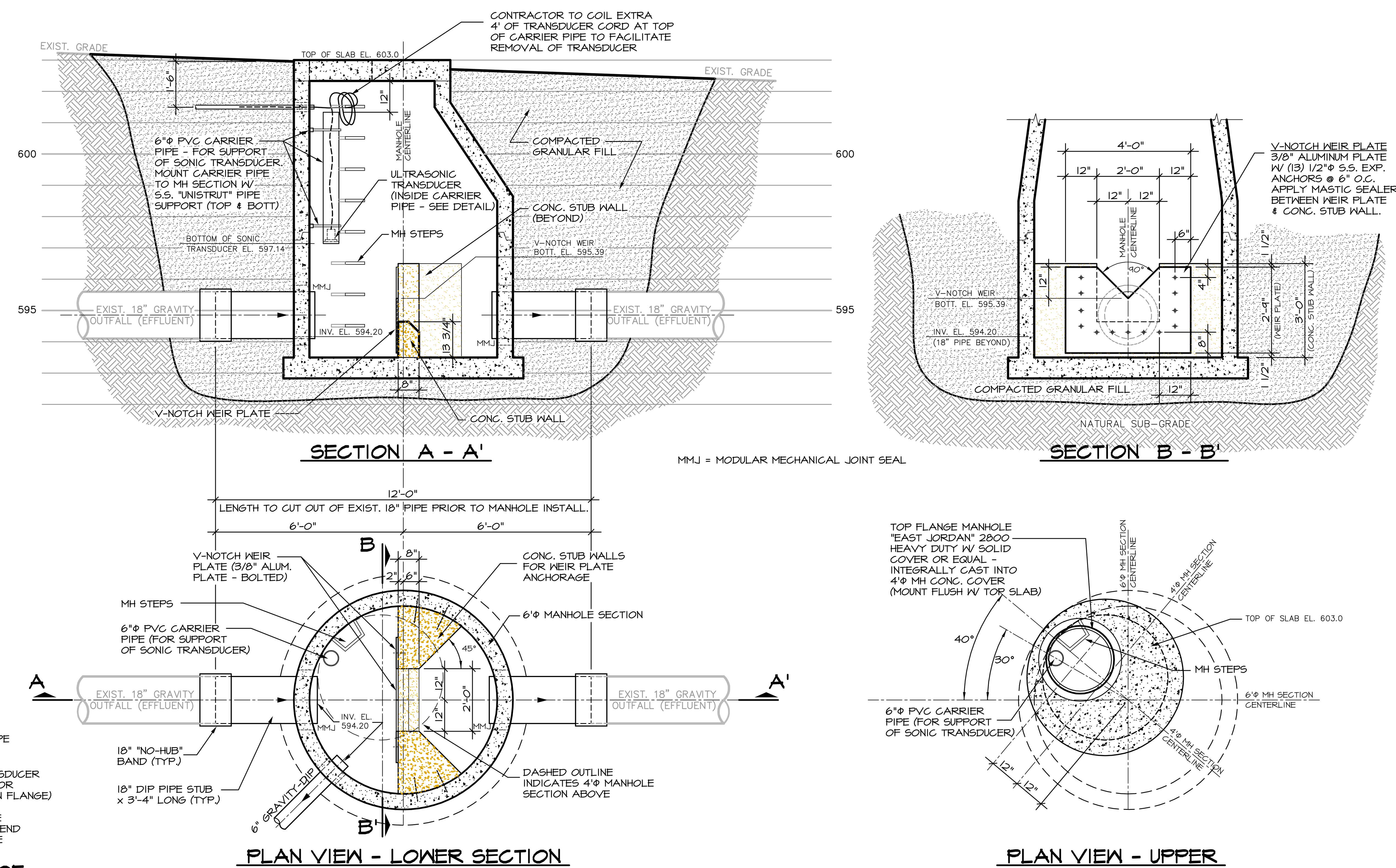
TRENCH BELOW DRIVING SURFACE OR STRUCTURE

NO SCALE



TRENCH NOT ADJACENT TO DRIVING SURFACE OR STRUCTURE

NO SCALE



"V" NOTCH WEIR CHAMBER DETAILS

SCALE: 3/8" = 1'-0"

NO.	REVISIONS	BY	DATE
	REVISED IN ACCORDANCE WITH CONSTRUCTION RECORDS		

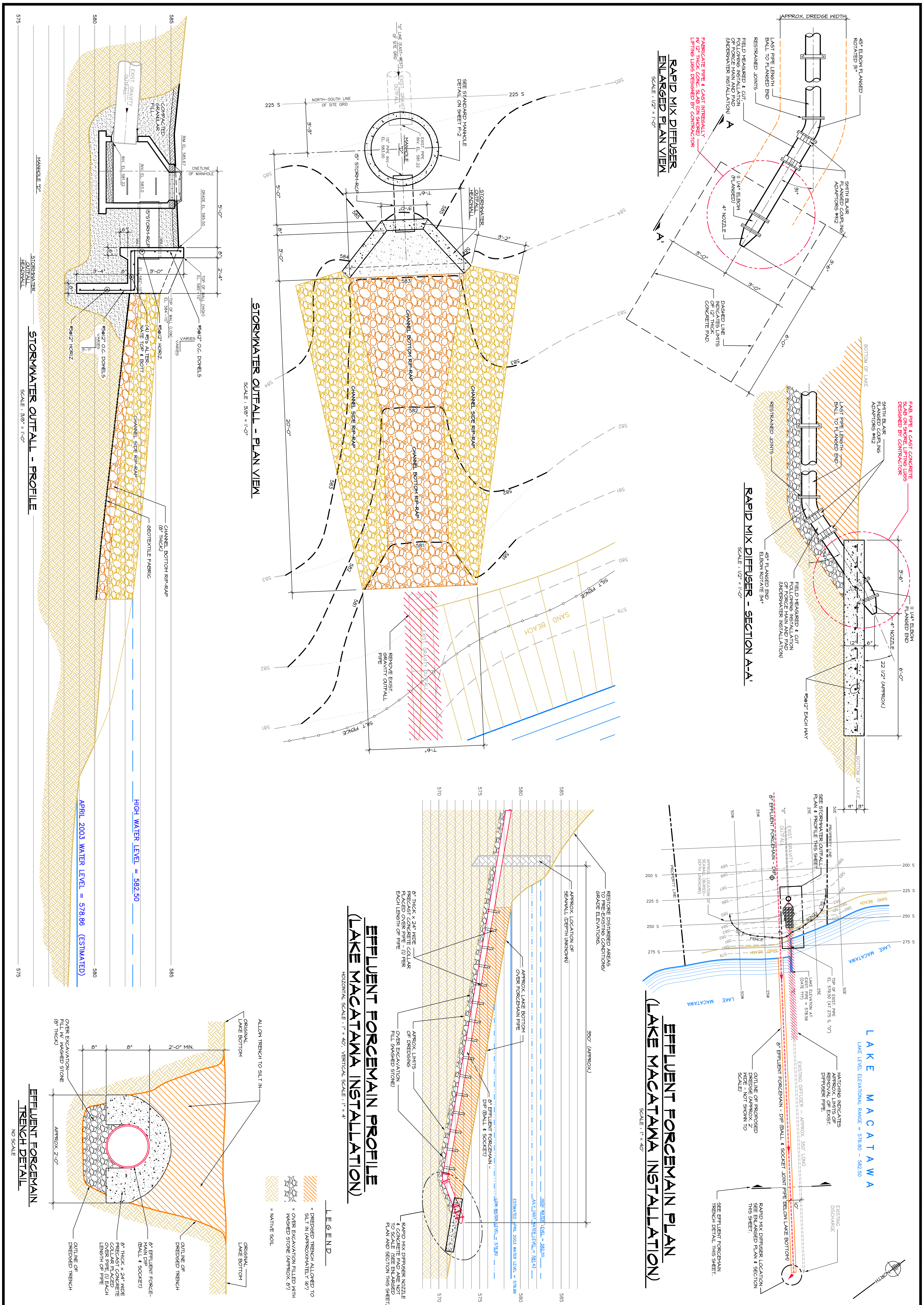
DRAWN BY: KJB
DESIGN BY: BLR
DATE: 12/12/03
FILE NO.: P2

CDR PIGMENTS
471 HOWARD AVENUE, HOLLAND, MICHIGAN
W.W.T.P. MODIFICATIONS

ROSE & WESTRA, INC.
ENVIRONMENTAL CONSULTANTS
Grand Rapids, Michigan

PROJECT NO. 0286.01379.3

SHEET NO. P-2



P-3	PROJECT NO. 0286013793 SHEET NO.	ROSE & WESTRA, INC. ENVIRONMENTAL CONSULTANTS Grand Rapids, Michigan

CDR PIGMENTS
471 HOWARD AVENUE, HOLLAND, MICHIGAN
W.W.T.P. MODIFICATIONS

NO.	REVISIONS	BY	DATE
	REVISED IN ACCORDANCE WITH CONSTRUCTION RECORDS		

FILE NO: P3
DRAWN BY: KJB
DESIGN BY: BLR
DATE: 12/12/03

Appendix C

Soil Grain Size Results

Table: Sediment Grain Size Results – Surface Sediments

Sample ID	Depth Interval	< 4 µ	4-75 µ	2000-4750 µ	425-2000 µ	75- 425 µ	>4750 µ
SD21-0-SD-11A-S	0 - 0.5 ft	-0.3	2.4	0.5	24.5	72.9	0.1
SD22-0-SD-11A-S	0 - 0.5 ft	0.3	0.2	1	21.2	76.8	0.5
SD23-0-SD-11A-S	0 - 0.5 ft	3.5	1	1.8	13.6	79.5	0.5
SD24-0-SD-11A-S	0 - 0.5 ft	9.2	23.8	1.1	5.9	59.2	0.8
SD25-0-SD-11A-S	0 - 0.5 ft	24.1	38	0.5	5.9	31.5	0
SD26-0-SD-11A-S	0 - 0.5 ft	18.2	15.3	1.1	4	60.8	0.6
SD27-0-SD-11A-S	0 - 0.5 ft	1.1	1.8	1.8	15.3	78	2
SD28-0-SD-11A-S	0 - 0.5 ft	24.8	37.3	0.5	3.4	34	0
SD29-0-SD-11A-S	0 - 0.5 ft	42.4	46.2	0.4	2.4	8.6	0
SD30-0-SD-11A-S	0 - 0.5 ft	37.8	36.1	0.5	4.5	21.1	0
SD31-0-SD-11A-S	0 - 0.5 ft	36.1	53.7	0.1	0.8	9.3	0
SD32-0-SD-11A-S	0 - 0.5 ft	38.3	46.4	0.1	1.7	13.5	0
SD33-0-SD-11A-D	0 - 0.5 ft	54.7	37.7	0	1.5	6.1	0
SD33-0-SD-11A-S	0 - 0.5 ft	56.7	35.8	0.4	1	6.1	0
SD34-0-SD-11A-S	0 - 0.5 ft	42.6	43	0	2.5	11.9	0
SD35-0-SD-11A-S	0 - 0.5 ft	44.3	48.8	0	0.9	6	0
SD36-0-SD-11A-D	0 - 0.5 ft	39.8	51.7	0.1	0.4	8	0
SD36-0-SD-11A-S	0 - 0.5 ft	37	54.2	0.1	0.4	8.3	0
SD37-0-SD-11A-S	0 - 0.5 ft	42.3	48.5	0.1	0.8	8.3	0
SD38-0-SD-11A-S	0 - 0.5 ft	50.9	45.6	0.1	0.4	3	0
SD39-0-SD-11A-S	0 - 0.5 ft	46.7	39.8	0	2.3	11.2	0
SD40-0-SD-11A-S	0 - 0.5 ft	48.5	36	0.8	2.3	12.4	0
SD41-0-SD-11A-S	0 - 0.5 ft	51	41.3	0	0.8	6.9	0
SD42-0-SD-11A-S	0 - 0.5 ft	46.3	46.8	0	0.9	6	0
SD43-0-SD-11A-S	0 - 0.5 ft	27.3	67.7	0	1.6	3.4	0
SD44-0-SD-11A-S	0 - 0.5 ft	1.2	87	0.1	1.6	10.1	0
SD45-0-SD-11A-D	0 - 0.5 ft	3	6.7	0.3	14.8	75.2	0
SD45-0-SD-11A-S	0 - 0.5 ft	2.8	6.5	0.3	14.5	75.9	0
SD46-0-SD-11A-S	0 - 0.5 ft	0.9	0.7	5.5	68.4	23.9	0.6
SD47-0-SD-11A-S	0 - 0.5 ft	44.5	48.2	0	0.9	6.4	0
SD48-0-SD-11A-S	0 - 0.5 ft	49.7	49.2	0	0.2	0.9	0
SD49-0-SD-11A-S	0 - 0.5 ft	4	3.6	1.5	13.2	77.4	0.3
SD50-0-SD-11A-S	0 - 0.5 ft	42.4	47.1	0.3	2.4	7.8	0
SD51-0-SD-11A-D	0 - 0.5 ft	42.6	39.3	0	2.8	15.3	0
SD51-0-SD-11A-S	0 - 0.5 ft	42	40.8	0.2	2.5	14.5	0
SD52-0-SD-11A-S	0 - 0.5 ft	39.2	45	0.1	2.4	13.3	0
SD53-0-SD-11A-S	0 - 0.5 ft	31.7	52.6	0.2	2.6	12.9	0
SD54-0-SD-11A-S	0 - 0.5 ft	27.4	63.6	0.1	1.6	7.3	0
SD55-0-SD-11A-S	0 - 0.5 ft	33.3	44.3	0.3	2.4	19.7	0
SD56-0-SD-11A-S	0 - 0.5 ft	10.6	9.9	1.2	5.6	72.7	0

Table : Sediment Grain Size Results – Subsurface Sediments

Sample ID	Depth Interval	< 4 µ	4-75 µ	2000-4750 µ	425-2000 µ	75- 425 µ	>4750 µ
SD23-0.5-2-SD-11A-S	0.5 - 2 ft	18.8	38.8	1.3	5.7	32.3	3.1
SD24-0.5-2-SD-11A-S	0.5 - 2 ft	10	42.3	0.4	1.5	45.5	0.3
SD25-0.5-2-SD-11A-S	0.5 - 2 ft	14.8	14.7	3.1	20.9	38.7	7.8
SD26-0.5-2-SD-11A-S	0.5 - 2 ft	5.3	3.4	3.4	29.8	57.1	1
SD28-0.5-2-SD-11A-S	0.5 - 2 ft	49.3	47.2	0	0.6	2.9	0
SD31-0.5-2-SD-11A-S	0.5 - 2 ft	43.7	49.7	0.3	1.1	5.2	0
SD34-0.5-2-SD-11A-S	0.5 - 2 ft	33.2	61.4	0	1.3	4.1	0
SD35-0.5-2-SD-11A-S	0.5 - 2 ft	48.6	46.8	0.3	0.6	2.6	1.1
SD36-0.5-2-SD-11A-S	0.5 - 2 ft	40.5	43.2	0	2	14.3	0
SD39-0.5-2-SD-11A-S	0.5 - 2 ft	52	45.3	0	0.6	2.1	0
SD40-0.5-2-SD-11A-S	0.5 - 2 ft	41.3	55.6	0	0.6	2.5	0
SD42-0.5-2-SD-11A-S	0.5 - 2 ft	55.9	43.3	0	0.1	0.7	0
SD44-0.5-2-SD-11A-S	0.5 - 2 ft	42.5	55.4	0	0.6	1.5	0
SD49-0.5-2-SD-11A-S	0.5 - 2 ft	2.7	2.4	2.4	19	66.2	7.4
SD50-0.5-2-SD-11A-S	0.5 - 2 ft	57.9	41.3	0	0.2	0.6	0
SD51-0.5-2-SD-11A-S	0.5 - 2 ft	54.7	42.6	0	0.8	1.9	0
SD52-0.5-2-SD-11A-S	0.5 - 2 ft	63.9	31.9	0	1.2	3	0
SD53-0.5-2-SD-11A-S	0.5 - 2 ft	49.4	47.2	0	1	2.4	0
SD54-0.5-2-SD-11A-S	0.5 - 2 ft	40.1	55.8	0	1	3.1	0
SD56-0.5-2-SD-11A-S	0.5 - 2 ft	53.8	32.7	0.1	1.6	11.8	0
SD25-2-3-SD-11A-S	2 - 3 ft	2.6	2.5	5.9	37.3	47.3	4.4
SD26-2-3-SD-11A-S	2 - 3 ft	1.4	2.9	2.9	17.2	71.1	4.5
SD23-2-4-SD-11A-S	2 - 4 ft	21.9	70.2	0	0.7	7.2	0
SD24-2-4-SD-11A-S	2 - 4 ft	2.6	20.1	0	0.2	77.2	0
SD28-2-4-SD-11A-S	2 - 4 ft	59.5	38.9	0	0.4	1.2	0
SD31-2-4-SD-11A-S	2 - 4 ft	55.3	43	0.7	0.3	0.4	0.3
SD34-2-4-SD-11A-S	2 - 4 ft	37.7	59.5	0	0.6	2.2	0
SD35-2-4-SD-11A-S	2 - 4 ft	65.8	34.1	0	0.1	0	0
SD36-2-4-SD-11A-S	2 - 4 ft	48.2	49.4	0	0.5	1.9	0
SD39-2-4-SD-11A-S	2 - 4 ft	58.4	40.6	0	0.3	0.7	0
SD40-2-4-SD-11A-S	2 - 4 ft	57.4	42	0	0.2	0.4	0
SD42-2-4-SD-11A-S	2 - 4 ft	56.7	41.8	0	0.7	0.8	0
SD44-2-4-SD-11A-S	2 - 4 ft	61.8	37.3	0	0.5	0.4	0
SD50-2-4-SD-11A-S	2 - 4 ft	53.1	27.6	0.1	1.9	17.2	0.1
SD51-2-4-SD-11A-S	2 - 4 ft	62.9	37	0	0.1	0	0
SD52-2-4-SD-11A-S	2 - 4 ft	64.9	33.6	0	0.7	0.8	0
SD53-2-4-SD-11A-S	2 - 4 ft	60.9	37.1	0	0.7	1.3	0
SD54-2-4-SD-11A-S	2 - 4 ft	65.1	33.6	0	0.6	0.7	0
SD55-2-4-SD-11A-S	2 - 4 ft	61.4	36.6	0	0.6	1.4	0
SD56-2-4-SD-11A-S	2 - 4 ft	52.6	32.9	0	2.7	11.8	0

Appendix D

Sediment Stability Analysis

Introduction/Objective

This appendix provides a sediment stability analysis that has been prepared to evaluate the potential for scour of sand backfill material to be placed in the Lake Macatawa dredge footprint at the former BASF Holland, Michigan facility. This analysis evaluates the potential effects of recreational propeller (prop) wash, wave action, and storm and current erosion under both un-remediated (current condition) and sand-backfilled (future condition) scenarios. It was determined that propeller wash is the critical case for the sand backfill area(s) with the greatest potential to create scour of any appreciable depth. As described below, much of this analysis conservatively focuses on potential sheer stresses associated with vessel traffic from the nearby private marinas and docks. The analysis addresses the potential to disturb the sand backfill at the former BASF facility and calculates the potential depth of scour from the vessel operations for the new sand backfill and the existing silt lake bottom.

The Corrective Measures Implentation Work Plan (CMIWP) defines a focused sediment removal action that includes the mechanical dredging of surficial sediments (up to 4 feet deep) and the placement of sand backfill over the dredged areas. The sand backfill will be up to 4 feet thick and placed to approximately replicate the pre-dredge grade(s). The assumed median diameter of the sand backfill material is 0.4 mm (medium to coarse sand). The sand backfill has been assessed for scour potential from the likely vessel traffic and then compared to the potential scour of the existing silt lake bed.

Background Information

Site Description

The historic BASF facility and neaby condominium marina is shown below in Figure 1. The dredge/backfill areas are shown in red. Lake Macatawa has an ordinary high water level of 582.5 ft NAVD88 and ordinary low water level of 576.8 ft NAVD88. The dredge/backfill area is in water depths (at ordinary low water) of 3.3 ft. to 6.3 ft. approximately.

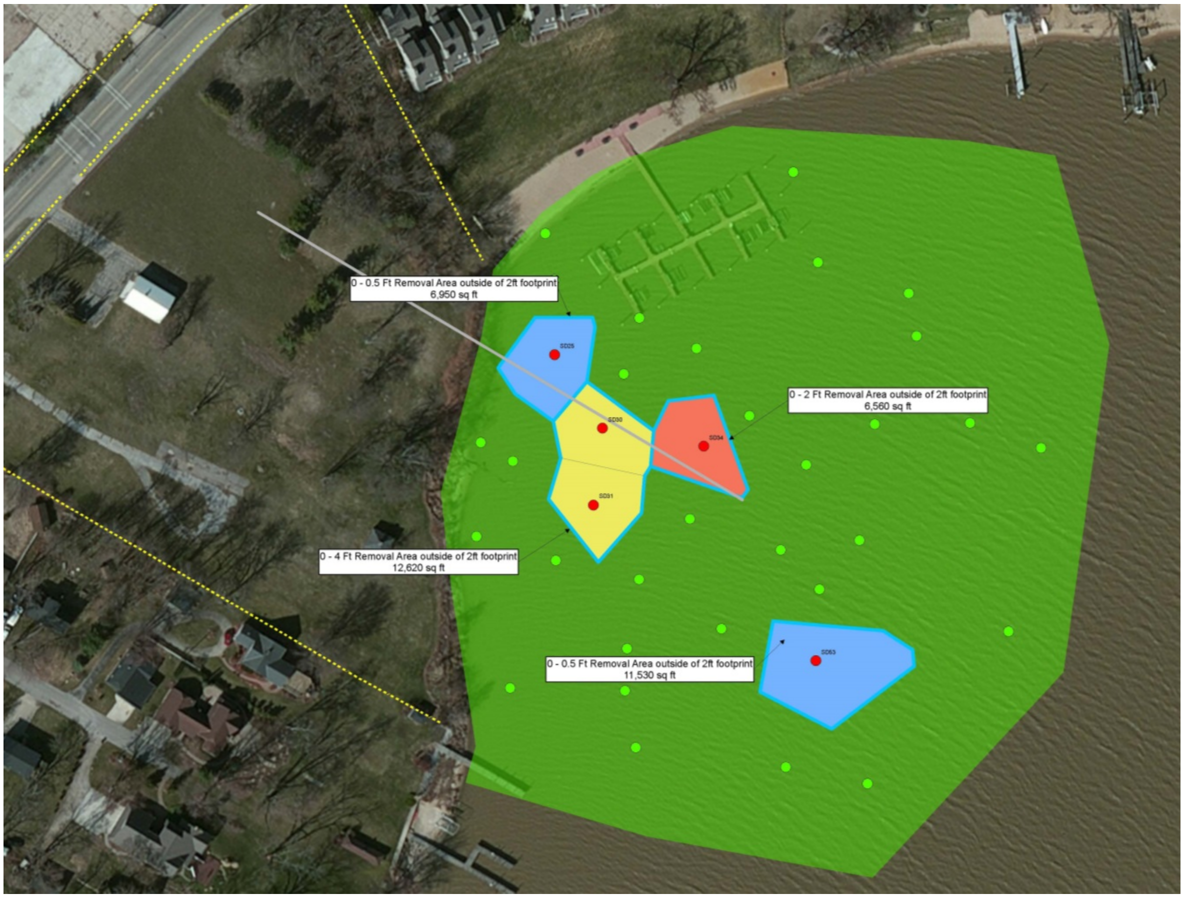


Figure 1 BASF Facility on Lake Macatawa and Dredge/Backfill Areas

The slips at the neighboring condo marina measure approximately 28 feet in length.

Sediment and Sand Backfill Characteristics and Critical Bed Velocities

It is assumed that the sand backfill to be used at the BASF site will be a medium to coarse sand with a median grain size (D50) of approximately 0.4mm.

The software tool, Sedtrans 05, was used to determine the critical velocities required to begin mobilization of the median size sand grains in the sand backfill. Sedtrans 05 is a sediment transport model for continental shelf and estuaries based on sediment mobility equations developed by van Rijn (1993). The velocities produced by prop wash are expressed as a current speed. Table 3 lists the modeled sand grain size and the associated critical velocity.

Table 2 Critical Bed Velocities for Sand Mobilization (Sedtrans 05 model output)

Sediment Size (mm)	Current Speed (feet/second)
0.4	1.3
0.0156 [b]	1.5

(a) Calcuated for non cohesive sediments in Sedtrans 05

(b) Calculated from typical values for fine silt

Evaluation of Potential Factors Affecting Sediment Stability

The project location is a relatively sheltered area at the northeast end of Lake Macatawa where impacts from storm generated waves and vessel wakes are limited/minimal. The Macatawa river enters the lake at the eastern end and the main river flow runs along the southern edge of the lake where a navigation channel is marked for large boats (Department of Natural Resources, Michigan,1941). Navigation channels are often chosen in areas that are naturally deep (often due to river velocities scouring the sediment) to minimize the maintenance dredging expense. The project location on the northern shore most likely has low river velocities/currents compared to the rest of the lake and is a net depositional area where sediment accumulates over time and long term natural erosion is minimal. The sediment cores collected at the Site confirm this, with silt dominating the sediment profile.

The project location has a maximum wind fetch (distance over water) to the south-southeast direction of approximately 0.54 miles. Wind speeds and directions were assessed over the previous year and a maximum speed from the south-southeast direction of 32.2 mph (blowing for the 2 hours and 24 minutes necessary to achieve fully developed wave conditions) was determined. This maximum wind speed of 32.2 mph was confirmed using wind data recorded between December 2000 to December 2012 by the Western Regional Climate Center at the Western Michigan Regional Airport approximately 3.7 miles south of the project location. Wind/wave hindcasting methods by the Shore Protection Manual (USACE 1984) were used to determine a fully developed (fetch limited) deepwater wave height of 1.2 feet and wave period of 1.7 seconds. Linear wave theory was used to determine a shoaled wave height of 1.1 feet in a water depth of approximately 4 feet (the backfill area has a range of depths but the 4 foot depth was selected as the shallowest that a recreational boater would likely be expected to operate in, as discussed in later sections). This wave would equate to a bottom velocity of approximately 0.6 feet/sec. This could induce incipient motion in the silt lake bed however, site investigations found that the existing grain size varied little within individual geotechnical corings (AECOM, 2016) indicating minimal storm wave impact (natural sorting of material by grain size) and overall sediment stability in the project area. The sand in the backfill material is mobilized with velocities greater than 1.3 feet/sec which indicates minimal disturbance by storm wind waves in a water depth to 4 feet.

Based on this analysis, it was concluded that propeller wash produced by recreational boats common on the lake has the greatest potential to disturb the sand backfill. Propeller velocities are greater than those produced by waves or currents and are more localized to cause scour in the lake bed or backfill material.

Vessel Characteristics and Boat Operation Scenarios

The vessels most likely to be traversing the dredge/backfill areas are recreational boats under 28 feet in length with engines of up to 200 horsepower. For prop wash modeling purposes, the Regal 2250 was chosen as a representative vessel for the analysis, the vessel characteristics are summarized in Table 1 below. The typical draft for these types of vessels is up to approximately 36 inches with the drive down and 22 inches with the drive up (the Regal 2250 draft with drive down is 34 inches, 18 inches with drive up). The assumed motor is a 200 horsepower Volvo, or equivalent, with a 10 inch diameter propeller.

Table 1 Vessel Characteristics

Representative Vessel	Length overall (ft)	Draft drive down (in)	Engine Power (hp)	Engine power assumed for scenarios (%)	No. of Propellers	Prop. Diameter (in)
Regal 2250	22' 2"	34	200	15 & 10%[(a)]	1	10

(c) Two scenarios were evaluated for a vessel accerating using 10 and 15% of the engine power. It was assumed that the boat operator would not go immediately to full throttle in shallow water and would accelerate in a more controlled manner until they got into deeper water. As vessel speed increases (acceleration /engine power) time over a bottom location and potential scour impact decreases.

It is possible that recreational vessels will be travelling over the dredge/backfill areas at higher speeds (faster than 10 mph). Research by Beachler and Hill (Beacher & Hill 2003) showed that small recreational vessels travelling faster than 10 to 12 mph don't produce significant bottom velocities at the lake bottom because the boat is "on plane", or close to, and at this speed the propeller is pointed parallel to the water surface. Tests by Beachler & Hill in 0.61m water depth measured bottom velocities of approximately 10 cm/sec (0.3 ft/sec) with a boat traveling at 15 mph (Figure 2).

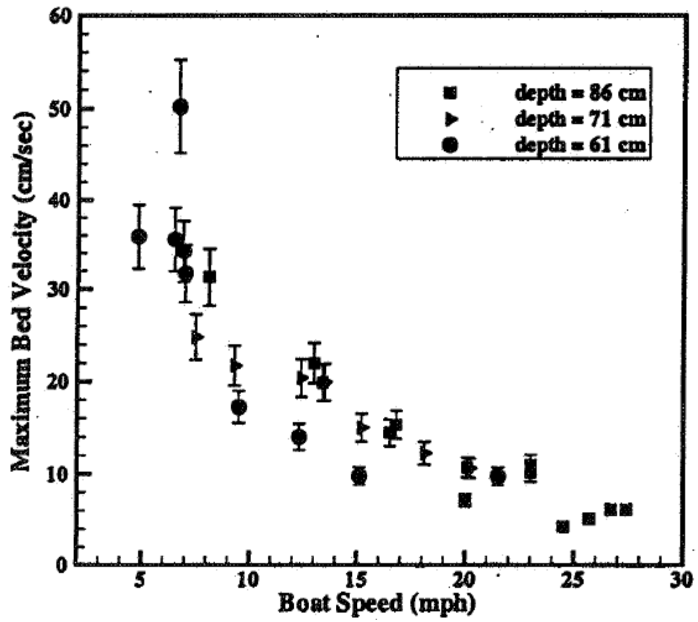


Figure 2 **Observed values of maximum bed velocity as function of water depth and boat speed for recreational watercraft (Figure 9, Beachler & Hill, 2003)**

The study areas evaluated by Beachler and Hill (2003) used lakes with a sandy bottom and median grain size of about 0.3 mm. In addition, at higher speeds the time which any propeller generated flow/turbulence can interact with a specific bottom location is limited enough to cause little or no disturbance. Boats traveling at, or accelerating from, slower speeds may have the propeller directed at a downward angle toward the lake bed depending on vessel and drive trim angles; however, the maximum bed velocities for a recreational boat essentially at idle are minimal (a boat traveling at 7 ft/sec or 4 mph with the lakebed 1 foot below the propeller produces a maximum bottom velocity of approximately 1 ft/sec, using equations developed by Verhey (1983), Blaaus & de Kaa (1978), and Maynord (1998)). Small recreational boats travelling at higher speeds (faster than 10 to 12 mph) have been shown to not significantly affect the lake bottom in research by Beechler & Hill (2003) since the boat is travelling "on plane" and the propeller is pointed parallel to the water surface and not at the lake bed. The boat is also sitting slightly higher in the water when travelling on plane.

Therefore, the worst case for the sand backfill area and the existing silt lake bed would be a recreational boat that is idling or traveling at slow speed and starting to accelerate. The boat has not reached "on plane" yet and the propeller may be angled towards the lake bed. The sand backfill and existing silt lake bed have been evaluated for scour potential using this scenario.

Calculation of Propeller Induced Bottom Velocities and Resulting Scour Impacts

Vessel Operations over the Backfill Area

Most recreational boats in the area will be traversing the dredge/backfill areas at slow speeds to or from private docks or the nearby condominium marina. The sediment stability analysis focused on a conservative case that evaluated potential sheer stresses from a small motorized vessel idling, or traveling at slow speed, over the project area before starting to accelerate. This is the critical time that a propeller could be directed at an angle towards the sand backfill and working to accelerate the vessel with the vessel traveling at a slow enough speed to develop scour.

Water Depths and Distance of Propeller above the Lakebed

The lake bed elevations in the dredge/backfill area range from 570.5 to 573.5 ft NAVD88 (more shallow areas may exist but are outside of the depths that boaters would likely be expected to operate in). Lake water levels range from an ordinary high water level of 582.5 ft NAVD88 and ordinary low of 576.8 ft. NAVD88. This results in water depths in the backfill area ranging from 3.3 to 12 feet at ordinary low and ordinary high water respectively, shown in Figure 3 below. It is assumed that a 4 foot water depth is the shallowest that the boaters will be operating in and the most conservative analyzed case for the sand backfill. An operator traversing the backfill area may encounter shallower depths, bottom out the boat and use the engine to get free, but this is assumed to be a rare scenario and therefore not a valid analysis scenario.

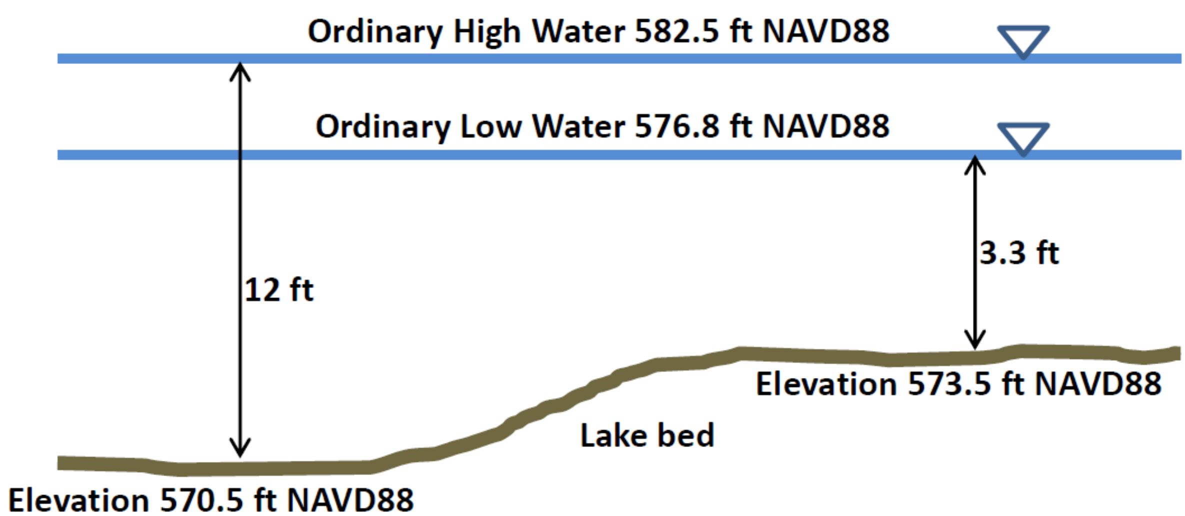


Figure 3 Ilustrative sketch for lake depths and water levels at Lake Macatawa backfill areas

The representative vessel at idle has a drive down draft of approximately 34 inches. In a water depth of 4 feet, this gives a distance between the tip of the propeller and the lake bed of 1.1 feet (approximately 1.5 feet from propeller shaft to bottom). A distance between the propeller shaft and the lakebed of 2 feet (approximate drive down prop tip to lake bed of 1.6 feet) is also analyzed. The 1.1+ feet is the shallowest distance between propeller tip and lakebed that it is assumed a boater would be traversing and comfortable accelerating from an idle.

Propeller and Scour Depth Calculations

Propeller velocity calculations were made using research by Verhey (1983), Blaaus & de Kaa (1978), and Maynord (1998) that have been published in USEPA (1998). Figure 4 below is a definition sketch of how propeller wash calculations are used (PIANC, 2015). The sketch has been created for commericial vessels but is analagous for the small recreational boat case. The jet of water exiting the propeller is modeled as a cone extending out from the propeller center. Velocities are higher in close proximity to to the propeller center and decrease as the distance increases.This is why armored slopes underneath piled port structures are vulnerable because due to their location, they are directly in line to encounter Vmax propeller velocities. The bottom velocity, Vb, tends to be smaller as the propeller velocity attenuates towards the lake bottom. Bottom velocities were found to be quite small for recreational boat propellers as shown by Beachler & Hill (2003) and did not disturb the bottom sandy sediments in water depths as shallow as 0.6m and boat speeds of 15 mph (Figure 2 above).

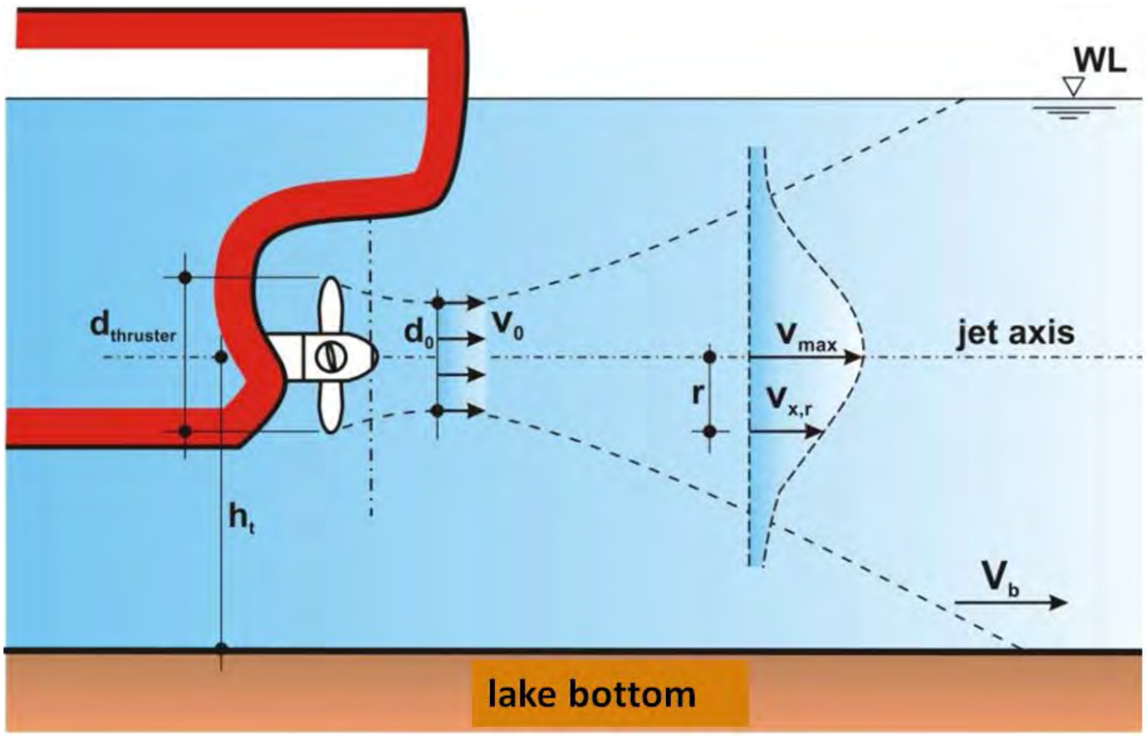


Figure 4 **Definition sketch of prop wash variables for propeller (PIANC 2015). The propeller in this image is shown level with the boat hull; however, for the Lake Macatawa recreational boat case, it is assumed the propeller extends below the hull**

The calculated values for bottom flow velocities and bottom shear stress are based on the methods presented in Blaauw and van de Kaa (1978), as referenced in Guidance for In-Situ Subaqueous Capping of Contaminated Sediments (USEPA, 1998). The critical parameters associated with the equations to determine the propeller wash forces include water depth, horse power, and the size of the propellers.

The maximum bottom velocity, V_b was calculated using the following empirical equation (Blaauw and van de Kaa 1978) :

$$V_b(\max) = C_1 U_o D_p / H_p$$

With:

Uo = jet velocity exiting the propeller
Hp = distance from propeller shaft to lake bed
Dp = main propeller diameter
C1 = 0.22 for non-ducted propeller, 0.33 for ducted propellers

The jet velocity exiting the propeller is given by Blaauw and van de Kaa (1978) as:

$$U_o = C_2 \left(\frac{P_d}{D_p^2} \right)^{1/3}$$

With:

U_o = jet velocity exiting the propeller in ft/sec
P_d = applied engine power/propeller in horsepower
D_p = main propeller diameter in feet
C_2 = 9.72 for non-ducted propeller, 7.68 for ducted propellers

The bottom velocities produced by the recreational boat in shallow water exceed the critical velocities for sand movement as determined with Sedtrans. The scour hole depth is approximated using the critical shear stresses and peak shear stress produced by the propeller to calculate the erosion rate of the sand layer. The erosion rate is using a method developed by the USACE called Sedflume which determines erosion parameters for an in-situ sediment coring. Those erosion parameters have been assumed for typical sediment characteristics for this calculation.

The peak shear stress is calculated by (Maynord, 2000):

$$\tau = 0.5 \rho_w C_{fs} V_{prop}^2$$

With:

ρ_w = water density
V_{prop} = Maximum bottom velocity from the propeller
C_{fs} = bottom friction factor for propeller wash, also called C_{fp}

The bottom friction factor (Maynord, 2000) is calculated as 1% of the propeller diameter divided by the distance between the propeller shaft and the lakebed.

The Sedflume erosion rate can be calculated by the following for coarse-grained, non cohesive sediments (Lick, 2009):

$$E = A(\tau - \tau_c)^n$$

With:

τ = Shear stress from propeller wash
τ_c = Critical bed stress
And A,n are erosion parameters from the SedFlume testing.

The existing silt lakebed was also assessed for scour potential and the erosion rate for fine-grained, cohesive sediments can be calculated by (Lick, 2009):

$$E = 10^{-4}\left(\frac{\tau}{\tau_c}\right)^n$$

Results and Conclusions

The maximum bottom velocity for three different scenarios using a small, recreational boat was calculated. The peak shear stress was then calculated to estimate the amount of sand or silt mobilized and the final depth of scour. As the scour hole deepens, the bottom velocity and peak shear stress were recalculated for the new depth and the erosion rate calculated. The total erosion is calculated for one second which is a conservative estimate for a boat propeller to be directed at the same location in the sand cover or lakebed. The approximate near bed velocities are shown in Table 3 below for the three scenarios.

Table 3 Near Bed Velocities from AnalyzedVessel Operations

Vessel	Scenario	Depth between prop shaft and lake bed (ft)	% of Engine Power	Approx. Max Near Bed Velocity (ft/sec)
Regal 2250	1	1.5	10	3.6
	2	1.5	15	4.1
	3	2	15	3.1

Table 4 Scour Hole Depths for Sand Cover and Existing Silt Lakebed

Scenario	Sand Hole Depth (in)	Silt Hole Depth (in)
1	4.6	11.9
2	6.7	20.8
3	1.7	5.3

The depth of the scour hole is shown in Table 4 for the sand backfill and the existing silt lakebed. The maximum sand scour hole is estimated at just under 7 inches and the maximum for silt to be just under 21 inches. Again, this is a conservative estimate for vessel operations over the backfill area(s) due to the following factors:

- In-situ silt in Lake Macatawa is most likely to be consolidated with the layers becoming more consolidated the further the silt is below the lakebed; however the model assumed the silt had uniform erosion parameters and no increasing consolidation with depth.
- A boat that is idling or traveling slowly and then accelerating will be moving forward and not impacting an isolated bottom location. To provide a conservative evaluation of potential scour, duration of 1 second at a fixed location was assumed for analysis.
- Most sand grains that are mobilized by propeller induced turbulence will not travel far from their original location and quickly settle back to the bottom. Bottom scour will likely be rapidly filled back in with mobilized sand grains or side slope sloughing.
- Although uncertainty could be explored further through the use of a more complex computational numerical model, which could provide greater resolution of the magnitude of the prop wash near bed velocity and scour hole depth, the calculated values presented herein provide an upper bound estimate of near bed velocities and scour depths for a conservative scenario.

In summary, this analysis demonstrates that: (1) sheer stresses from natural sources in this area (current, wave action, storms, etc.) are likely to be less than the potential sheer stresses associated with recreational vessel use in this area; (2) a conservative analysis of silty material (native material under current conditions) sediment stability indicates that this material would be potentially mobilized by a recreation vessel to depths of less than 2 ft; (3) even under conservative analysis assumptions, the sheer stresses from a recreational vessel are unlikely to substantively disturb the sand backfill; (4) if any disturbance of sand backfill were to occur, the maximum sand scour hole based on analysis would be less than 7 inches, and it is likely that the disturbed sand scour hole would rapidly backfill as mobilized sand particles settle back into the hole.

Based on this analysis, it can be concluded that sub-surface sediments at this Site (below 24 inches) are unlikely to be subject to scour potential under current conditions, and that in the future, sand backfill will limit potential scour to the upper 7 inches.

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AECOM Propeller Wash Calculations
Cover Page

AECOM
1111 3rd Avenue, Suite 1600
Seattle, WA 98101
(206) 438-2700

Client Name	BASF	**Project Number**		60150686-600	
Project Name	Lake Macatawa Sediment Stability				
Created by	K. Bridges	**Date**	28-Sep-16	**Page**	1
Checked by	WJG	**Date**	09 Oct, 2016	**of**	10

Subject

This spreadsheet estimates the maximum bottom velocity for three scenarios involving a small, recreational motor boat. The values are used in the subsequent spreadsheets to calculate the scour, if any, and approximate depth of scour hole for the three scenarios. The design vessel is a Regal 2250 boat that is 22 feet in length and uses a 200 hp Volvo motor with a 10 inch propeller that extends below the boat hull.

Description

Version Updates:

Instructions:
1) Each sheet contains general inputs that are needed to complete the calculations, these cells are highlighted yellow.
2) Calculations are performed in cells that are not highlighted.
3) Preliminary estimates are provided by each sheet in cells that are highlighted light green.

Spreadsheet Purpose:
Notes
Contains background information and references to equations used within this workbook.

Propeller Wash Calculation
Calculates the maximum bottom velocity for three events

Sand Erosion Calculations
Estimates the sand sediment movement and scour hole depth for each event using SedFlume parameters and shear stresses.

Silt Erosion Calculations
Estimates the silt sediment movement and scour hole depth for each event using SedFlume parameters and shear stresses.

Sedtrans
Shows a screenshot from the SedTrans calculation for bed velocity to mobilize a medium coarse grain of sand

AECOM (2012). "Appendix C Sediment Modeling Memoranda, Final Feasibility Study." Lower Duwamish Waterway, Seattle, WA

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Vessel	Boat Length (ft)	Boat Maximum Hull draft (ft)	Engine Make and Model	Engine HP	Prop Diameter (in)	Max Engine RPM
Regal 2250	22.2	2.8	Volvo Diesel D3 200 DP	200	10	4000

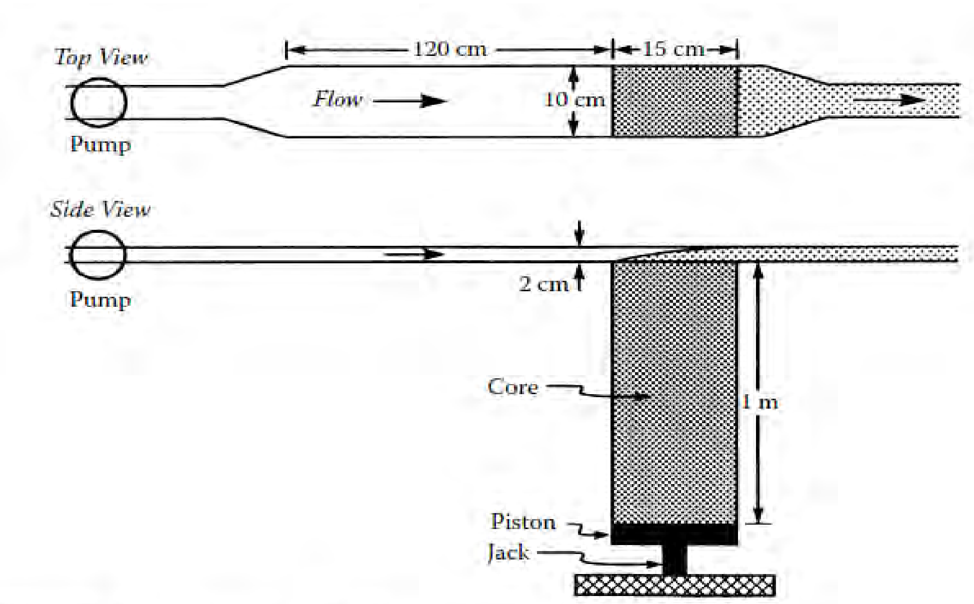

FIGURE 3.4 Schematic of Sedflume.

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Table 7. Critical shear stress by particle-size classification for determining approximate condition for sediment mobility at 20 degrees Celsius.

[Modified from Julien, 1998, table 7.1. Sediment mobility for a given particle size occurs when the bed shear stress exceeds the critical shear stress. Th **shear stress** (τ_c) calculated from equation 4 using particle diameters from this table. **Abbreviations:** φ, phi scale where φ = -log$_2$ (diameter in mm); n

Particle classification name	Ranges of particle diameters		Shields parameter (dimensionless)	Critical bed shear stress (τ_c) (N/m^2)
	φ	mm		
Coarse cobble	-7 – -8	128 – 256	0.054 – 0.054	112 – 223
Fine cobble	-6 – -7	64 – 128	0.052 – 0.054	53.8 – 112
Very coarse gravel	-5 – -6	32 – 64	0.05 – 0.052	25.9 – 53.8
Coarse gravel	-4 – -5	16 – 32	0.047 – 0.05	12.2 – 25.9
Medium gravel	-3 – -4	8 – 16	0.044 – 0.047	5.7 – 12.2
Fine gravel	-2 – -3	4 – 8	0.042 – 0.044	2.7 – 5.7
Very fine gravel	-1 – -2	2 – 4	0.039 – 0.042	1.3 – 2.7
Very coarse sand	0 – -1	1 – 2	0.029 – 0.039	0.47 – 1.3
Coarse sand	1 – 0	0.5 – 1	0.033 – 0.029	0.27 – 0.47
Medium sand	2 – 1	0.25 – 0.5	0.048 – 0.033	0.194 – 0.27
Fine sand	3 – 2	0.125 – 0.25	0.072 – 0.048	0.145 – 0.194
Very fine sand	4 – 3	0.0625 – 0.125	0.109 – 0.072	0.110 – 0.145
Coarse silt	5 – 4	0.0310 – 0.0625	0.165 – 0.109	0.0826 – 0.110
Medium silt	6 – 5	0.0156 – 0.0310	0.25 – 0.165	0.0630 – 0.0826
Fine silt	7 – 6	0.0078 – 0.0156	0.3 – 0.25	0.0378 – 0.0630

Appendix A - Propeller Wash Calculations

The vessels most likely to be traversing the dredge/backfill areas are recreational boats under 28 feet in length with engines of up to 200 horsepower, these are vessels most likely to be used at adjacent condominium docks. The Regal 2250 was chosen as a representative vessel for the analysis. The general vessel characteristics are, draft with drive down approximately 34 inches (18 inches with drive up), motor a 200 horsepower Volvo, or equivalent, with a 10 inch diameter propeller. This representative vessel was used in analysis to determine if scour from the estimated propeller wash would affect the coarse sand backfill material. Lake Macatawa has an ordinary high water level of 582.5 ft NAVD88 and ordinary low water level of 576.8 ft NAVD88. The dredge/backfill area is in water depths (at ordinary low water) of 3.3 ft. to 6.3 ft. approximately. Research by others shows that disturbance by recreational vessels to the lakebed is minimal after 10-12 mph because the boat is "on plane", the propeller is pointed parallel with the water surface and the prop is not over a given location for any significant amount of time. Therefore, vessels are assessed for the situation where the boat goes from idle, or slow speed, to accelerating over the sand backfill when the backfill can experience higher bottom velocities before the boat gets up to speed or "on plane". Situation 1 is the boat captain applying 10% power to accelerate over the backfill or existing silt bottom with 1.5 feet of water below the propeller shaft. Situation 2 is the boat captain applying 15% power to accelerate in 1.5 feet of water depth below the propeller shaft. Situation 3 is the same as Situation 2 except the depth below the prop is increased to 2 feet.

The calculated values for bottom flow velocities and bottom shear are based on the methods presented in Blaauw and Kaa (1978), as referenced in Guidance for In-Situ Subaqueous Capping of Contaminated Sediments (USEPA, 1998). The critical parameters associated with the equations to determine the propeller wash forces include water depth, horse power, and the size of the propellers.

Parameter	Description		Unit	Notes / References
Maximum Bottom Velocity	$V_{b(max)}$ =	$C_1 U_o D_p / H_p$	Ft/sec	Equation #1 (Eqn 3 in USEPA 1998)
Propeller Constant 1	C_1 =	0.22 for non-ducted propellers	Unitless	USEPA 1998
		0.30 for ducted propellers	Unitless	
Jet Velocity Exiting Propellers	U_o =	See Calculation Below	Ft/sec	
Applied Engine/Power Ratio	D_o =	0.71 D_p for non-ducted propeller	Ft	D_o=D_p for ducted propellers (Eqn 6 in USEPA 1998)
		D_p for ducted propellers	Ft	
Propeller Diameter	D_p =	Varies by Boat	Ft	D_o=0.85D_p for tunnel propellers (Verhey 1983)
Distance from Propeller Shaft to River Bottom	H_p =	River Depth - Maximum Draft	Ft	
Jet Velocity Exiting Propellers	U_o =	$C_2 * ((P_{dp}/(D_p^2))^{(1/3)}$	Ft/sec	Equation #2 (Eqn 4 in USEPA 1998)
Applied Engine/Propeller Power	P_{dp} =	Varies by Boat	hp	
Propeller Constant 2	C_2 =	9.72 for non-ducted propellers	Unitless	Eqn 4 in USEPA 1998
		7.68 for ducted propellers	Unitless	
Maximum Bottom Velocity	$V_{b(max)}$ =	$C_3(g(\delta)D_{50})^{1/2}$	Ft/sec	
Experimental Coefficient	C_3 =	0.6 for no movement	Unitless	Page A-10, USEPA 1998
		0.70 for small transport	Unitless	Page A-10, USEPA 1999
Gravitational Constant	g =	32.17	Ft/sec^2	

Mostly Likely Cases for Boats traveling within the cap area

Boat Description[1]	Units	Regal Bowrider 2250 Event 1	Event 2	Event 3
Rated horsepower per Engine	hp	200	200	200
Power Evaluated	%	10%	15%	15%
Applied Engine Power	hp	20	30	30
Number of propellers	Each	1	1	1
Propeller diameter (D_p)	Ft	0.83	0.83	0.83
Gear Ratio	Unitless	1.75	1.75	1.75
Propeller Slip	%	40	45	45
Propeller Pitch	in	19	19	19
Type of propeller (non-ducted or ducted)	Unitless	Non-Ducted	Non-Ducted	Non-Ducted
No movement or small transport expected for cap?	Unitless	Small transport	Small transport	Small transport
Applied Engineer/Power Ratio (D_o)	Unitless	0.59	0.59	0.59
Distance from Propeller Shaft to River Bottom (H_p)	Ft	1.50	1.50	2.00
Propeller Constant 1 (C_1)	Unitless	0.22	0.22	0.22
Propeller Constant 2 (C_2)	Unitless	9.72	9.72	9.72
Experimental Coefficient 3 (C_3)	Unitless	0.7	0.7	0.7
Jet Velocity Existing Propellers (U_o) (Using Equation #2)	Ft/sec	29.46	33.68	33.68
Boat Velocity	mph	11.2	11.7	11.7
Boat Velocity	Ft/sec	16.4	17.2	17.2
Maximum Bottom Velocity ($V_{b(max)}$) (Using Equation #1)	Ft/sec	3.60	4.12	3.09

Notes:
Ft = Feet
Ft/sec = feet per second
hp = horsepower

Typical value for representative motors. Value used to calculate boat speed (in gray, not used in calculation of flow velocity or stress)

References:
Blaaus, H.B., and E.J. van de Kaa. 1978. Erosion of bottom and Sloping Banks Caused by the Screw-Race of Maneuvering Ships. International Harbor Congress. Antwerp, Belgium. 1978.
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Scour Depth Calculations for Coarse Sand

This method uses critical shear stresses and peak shear stress produced by the propeller to calculate the erosion rate of the coarse sand layer. Erosion parameters for sand have been taken from SedFlume testing typical for the material. Total erosion depth is calculated based on the time that a boat propeller is expected to be stationary for. The table calculates the bottom velocity, peak shear stress, and erosion rate as the scour hole deepens.

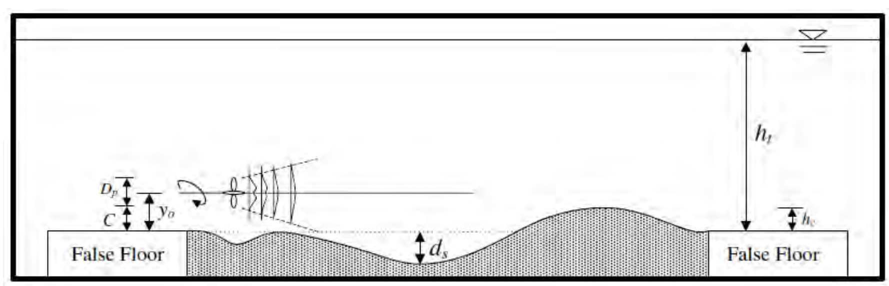
Parameters			Units	Notes
Water density	r	999.7	kg/m3	freshwater at 4 deg C
Clearance distance Propeller shaft to lakebed	C	0.46	m	
Propeller Diameter	Dp	0.25	m	Maximum expected prop size
Acceleration due to gravity	g	9.81	m/s2	
Efflux velocity from prop	Uo	8.98	m/s	Prop velocity calculated using USEPA 1998
Maximum bottom velocity	Vb	1.10	m/s	Prop velocity at bottom calculated using USEPA 1998
Calculations				
Local skin friction coefficient	$C_{f,p}$	0.0056	-	bottom friction factor for propeller wash
Peak shear stress	t_{peak}	3.35	N/m2	
Critical bed stress	t_{cr}	0.300	N/m2	From standard values for medium to coarse sand, range is 0.194 to 0.47 N/m2
Erosion Parameter A	A	0.1899	-	From USGS 2008 report using SedFlume parameters
Erosion Parameter n	n	2	-	Recommended by Lick (2009) for coarse grained sediments

Calculation Table

C (ft)	Vb (m/s)	t_{peak} (N/m2)	Erosion Rate (cm/s)	Max time (s)	Total Erosion (cm)	
1.50	1.10	3.3	19.59	0.125	2.4	
1.58	1.04	3.0	15.56	0.125	1.9	
1.64	1.00	2.8	13.04	0.125	1.6	
1.70	0.97	2.6	11.29	0.125	1.4	
1.74	0.94	2.5	9.99	0.125	1.2	
1.78	0.92	2.4	8.99	0.125	1.1	
1.82	0.90	2.3	8.18	0.125	1.0	
1.86	0.89	2.2	7.52	0.125	0.9	
			Total	**1**	**11.8**	cm
					4.6	inches

The table increases the depth below the prop (C) by incrementing in the amount that has been eroded. Bottom shear stress and bottom velocity is calculated for the new depth and a new erosion rate.

Note: Actual time that propeller will spend over the same square foot area of the sand backfill will be a fraction of a second when traveling. One second is used for the time as a conservative estimate.



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Peak bed shear stress is calculated by: (Maynord, 2000)

$$\tau = 0.5 \rho_w C_{fs} V_{prop}^2$$

Bottom friction factor for propeller wash is:

$$C_{fs} = 0.01 \left(\frac{D_p}{H_p} \right)$$

Erosion rate can be calculated by the following for coarse-grained, noncohesive sediments (Van Rijn, 1993)

$$\mathrm{E} = \mathrm{A}(\tau - \tau_c)^n$$

Where A and n are erosion parameters from SedFlume testing

Erosion rate can be calculated by the following for fine-grained, cohesive sediments (Lick, 2009)

$$\mathrm{E} = 10^{-4} \left(\frac{\tau}{\tau_c} \right)^n$$

Scour Depth Calculations for Coarse Sand

This method uses critical shear stresses and peak shear stress produced by the propeller to calculate the erosion rate of the coarse sand layer. Erosion parameters for sand have been taken from SedFlume testing typical for the material. Total erosion depth is calculated based on the time that a boat propeller is expected to be stationary for. The table calculates the bottom velocity, peak shear stress, and erosion rate as the scour hole deepens.

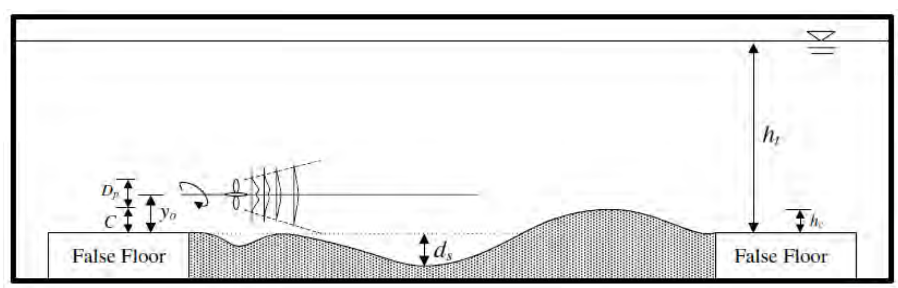
Parameters			Units	Notes
Water density	ρ	999.7	kg/m3	freshwater at 4 deg C
Clearance distance Propeller shaft to lakebed	C	0.46	m	
Propeller Diameter	Dp	0.25	m	Maximum expected prop size
Acceleration due to gravity	g	9.81	m/s2	
Efflux velocity from prop	Uo	10.27	m/s	Prop velocity calculated using USEPA 1998
Maximum bottom velocity	Vb	1.26	m/s	Prop velocity at bottom calculated using USEPA 1998
Calculations				
Local skin friction coefficient	$C_{f,p}$	0.0056	-	bottom friction factor for propeller wash
Peak shear stress	τ_{peak}	4.37	N/m2	
Critical bed stress	τ_{cr}	0.300	N/m2	From standard values for medium to coarse sand, range is 0.194 to 0.47 N/m2
Erosion Parameter A	A	0.1899	-	From USGS 2008 report using SedFlume parameters
Erosion Parameter n	n	2	-	Recommended by Lick (2009) for coarse grained sediments

Calculation Table

C (ft)	Vb (m/s)	τ_{peak} (N/m2)	Erosion Rate (cm/s)	Max time (s)	Total Erosion (cm)	
1.50	1.26	4.4	35.02	0.125	4.4	
1.64	1.15	3.6	23.58	0.125	2.9	
1.74	1.08	3.2	18.35	0.125	2.3	
1.82	1.04	3.0	15.22	0.125	1.9	
1.88	1.00	2.8	13.09	0.125	1.6	
1.93	0.97	2.6	11.53	0.125	1.4	
1.98	0.95	2.5	10.33	0.125	1.3	
2.02	0.93	2.4	9.38	0.125	1.2	
		Total		**1**	**17.1**	cm
					6.7	inches

The table increases the depth below the prop (C) by incrementing in the amount that has been eroded. Bottom shear stress and bottom velocity is calculated for the new depth and a new erosion rate.

Note: Actual time that propeller will spend over the same square foot area of the sand backfill will be a fraction of a second when traveling. One second is used for the time as a conservative estimate.



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Peak bed shear stress is calculated by: (Maynord, 2000)

$$\tau = 0.5 \rho_w C_{fs} V_{prop}^2$$

Bottom friction factor for propeller wash is:

$$C_{fs} = 0.01 \left(\frac{D_p}{H_p} \right)$$

Erosion rate can be calculated by the following for coarse-grained, noncohesive sediments (Van Rijn, 1993)

$$E = A(\tau - \tau_c)^n$$

Where A and n are erosion parameters from SedFlume testing

Erosion rate can be calculated by the following for fine-grained, cohesive sediments (Lick, 2009)

$$E = 10^{-4} \left(\frac{\tau}{\tau_c} \right)^n$$

Scour Depth Calculations for Coarse Sand

This method uses critical shear stresses and peak shear stress produced by the propeller to calculate the erosion rate of the coarse sand layer. Erosion parameters for sand have been taken from SedFlume testing typical for the material. Total erosion depth is calculated based on the time that a boat propeller is expected to be stationary for. The table calculates the bottom velocity, peak shear stress, and erosion rate as the scour hole deepens.

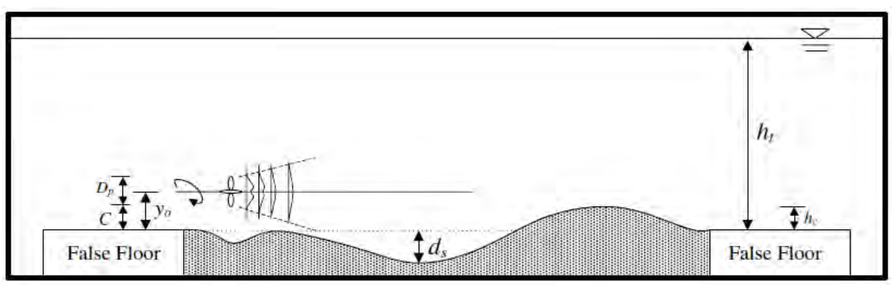
Parameters			Units	Notes
Water density	ρ	999.7	kg/m3	freshwater at 4 deg C
Clearance distance Propeller shaft to lakebed	C	0.61	m	
Propeller Diameter	Dp	0.25	m	Maximum expected prop size
Acceleration due to gravity	g	9.81	m/s2	
Efflux velocity from prop	Uo	10.27	m/s	Prop velocity calculated using USEPA 1998
Maximum bottom velocity	Vb	0.94	m/s	Prop velocity at bottom calculated using USEPA 1998
Calculations				
Local skin friction coefficient	$C_{f,p}$	0.0042	-	bottom friction factor for propeller wash
Peak shear stress	τ_{peak}	1.85	N/m2	
Critical bed stress	τ_{cr}	0.300	N/m2	From standard values for medium to coarse sand, range is 0.194 to 0.47 N/m2
Erosion Parameter A	A	0.1899	-	From USGS 2008 report using SedFlume parameters
Erosion Parameter n	n	2	-	Recommended by Lick (2009) for coarse grained sediments

Calculation Table

C (ft)	Vb (m/s)	τ_{peak} (N/m2)	Erosion Rate (cm/s)	Max time (s)	Total Erosion (cm)	
2.00	0.94	1.8	5.04	0.125	0.6	
2.02	0.93	1.8	4.80	0.125	0.6	
2.04	0.92	1.8	4.58	0.125	0.6	
2.06	0.91	1.7	4.38	0.125	0.5	
2.08	0.91	1.7	4.20	0.125	0.5	
2.09	0.90	1.7	4.03	0.125	0.5	
2.11	0.89	1.7	3.88	0.125	0.5	
2.13	0.89	1.6	3.74	0.125	0.5	
			Total	1	**4.3**	cm
					1.7	inches

The table increases the depth below the prop (C) by incrementing in the amount that has been eroded. Bottom shear stress and bottom velocity is calculated for the new depth and a new erosion rate.

Note: Actual time that propeller will spend over the same square foot area of the sand backfill will be a fraction of a second when traveling. One second is used for the time as a conservative estimate.



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Peak bed shear stress is calculated by: (Maynord, 2000)

$$\tau = 0.5\rho_w C_{fs} V_{prop}^2$$

Bottom friction factor for propeller wash is:

$$C_{fs} = 0.01\left(\frac{D_p}{H_p}\right)$$

Erosion rate can be calculated by the following for coarse-grained, noncohesive sediments (Van Rijn, 1993)

$$\mathrm{E} = \mathrm{A}(\tau - \tau_c)^n$$

Where A and n are erosion parameters from SedFlume testing

Erosion rate can be calculated by the following for fine-grained, cohesive sediments (Lick, 2009)

$$\mathrm{E} = 10^{-4}\left(\frac{\tau}{\tau_c}\right)^n$$

Scour Depth Calculations for Silt

This method uses critical shear stresses and peak shear stress produced by the propeller to calculate the erosion rate of the bottom silt. Erosion parameters for silt have been taken from Lower Duwamish Sedflume testing typical and critical shear stress is typical for fine silt. Total erosion depth is calculated for the time that a boat propeller is expected to be stationary for. The table calculates the bottom velocity, peak shear stress, and erosion rate as the scour hole deepens.

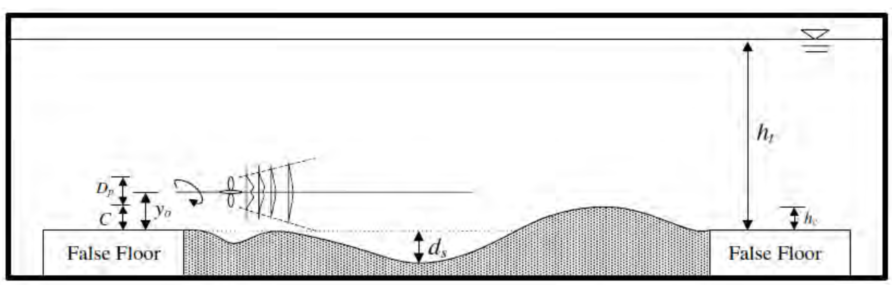
Parameters			Units	Notes
Water density	ρ	999.7	kg/m3	freshwater at 4 deg C
Clearance distance Propeller shaft to lakebed	C	0.46	m	
Propeller Diameter	Dp	0.25	m	Maximum expected prop size
Acceleration due to gravity	g	9.81	m/s2	
Efflux velocity from prop	Uo	8.98	m/s	Prop velocity calculated using USEPA 1998
Maximum bottom velocity	Vb	1.10	m/s	Prop velocity at bottom calculated using USEPA 1998
Calculations				
Local skin friction coefficient	$C_{f,p}$	0.0056	-	bottom friction factor for propeller wash
Peak shear stress	τ_{peak}	3.35	N/m2	
Critical bed stress	τ_{cr}	0.0378	N/m2	From standard values for fine silt. Range is 0.0378 to 0.0630 N/m2
Erosion Parameter n	n	3.2	-	From Lower Duwamish AECOM report

Calculation Table

C (ft)	Vb (m/s)	τ_{peak} (N/m2)	Erosion Rate (cm/s)	Max time (s)	Total Erosion (cm)	
1.50	1.10	3.3	170.18	0.125	21.3	
2.20	0.75	1.6	14.76	0.125	1.8	
2.26	0.73	1.5	12.40	0.125	1.6	
2.31	0.71	1.4	10.76	0.125	1.3	
2.35	0.70	1.4	9.53	0.125	1.2	
2.39	0.69	1.3	8.58	0.125	1.1	
2.43	0.68	1.3	7.81	0.125	1.0	
2.46	0.67	1.2	7.18	0.125	0.9	
				1	**30.1**	cm
					11.9	inches

The table increases the depth below the prop (C) by incrementing in the amount that has been eroded. Bottom shear stress and bottom velocity is calculated for the new depth and a new erosion rate.

Note: Actual time that propeller will spend over the same square foot area of the silt lake bed will be a fraction of a second when traveling. One second is used as a conservative estimate.



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Peak bed shear stress is calculated by: (Maynord, 2000)

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Where A and n are erosion parameters from SedFlume testing

Erosion rate can be calculated by the following for fine-grained, cohesive sediments (Lick, 2009)

$$\mathrm{E} = 10^{-4}\left(\frac{\tau}{\tau_c}\right)^n$$

Scour Depth Calculations for Silt

This method uses critical shear stresses and peak shear stress produced by the propeller to calculate the erosion rate of the bottom silt. Erosion parameters for silt have been taken from Lower Duwamish Sedflume testing typical and critical shear stress is typical for fine silt. Total erosion depth is calculated for the time that a boat propeller is expected to be stationary for. The table calculates the bottom velocity, peak shear stress, and erosion rate as the scour hole deepens.

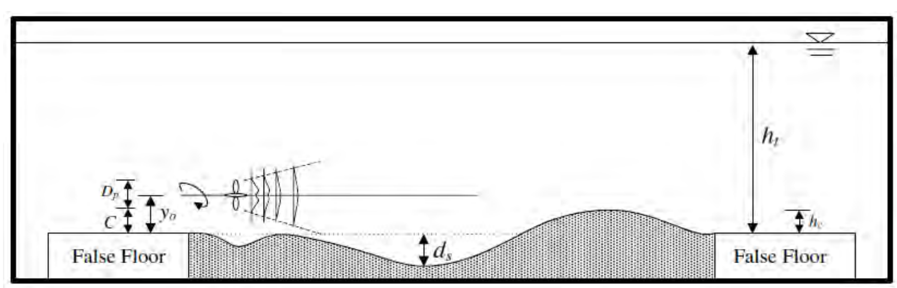
Parameters			Units	Notes
Water density	ρ	999.7	kg/m3	freshwater at 4 deg C
Clearance distance Propeller shaft to lakebed	C	0.46	m	
Propeller Diameter	Dp	0.25	m	Maximum expected prop size
Acceleration due to gravity	g	9.81	m/s2	
Efflux velocity from prop	Uo	10.27	m/s	Prop velocity calculated using USEPA 1998
Maximum bottom velocity	Vb	1.26	m/s	Prop velocity at bottom calculated using USEPA 1998
Calculations				
Local skin friction coefficient	$C_{f,p}$	0.0056	-	bottom friction factor for propeller wash
Peak shear stress	τ_{peak}	4.37	N/m2	
Critical bed stress	τ_{cr}	0.0378	N/m2	From standard values for fine silt. Range is 0.0378 to 0.0630 N/m2
Erosion Parameter n	n	3.2	-	From Lower Duwamish AECOM 2012 report

Calculation Table

C (ft)	Vb (m/s)	τ_{peak} (N/m2)	Erosion Rate (cm/s)	Max time (s)	Total Erosion (cm)	
1.50	1.26	4.4	400.70	0.125	50.1	
3.14	0.60	1.0	3.52	0.125	0.4	
3.16	0.60	1.0	3.42	0.125	0.4	
3.17	0.59	1.0	3.32	0.125	0.4	
3.19	0.59	1.0	3.23	0.125	0.4	
3.20	0.59	1.0	3.15	0.125	0.4	
3.21	0.59	1.0	3.07	0.125	0.4	
3.22	0.58	0.9	2.99	0.125	0.4	
				1	**52.9**	cm
					20.8	inches

The table increases the depth below the prop (C) by incrementing in the amount that has been eroded. Bottom shear stress and bottom velocity is calculated for the new depth and a new erosion rate.

Note: Actual time that propeller will spend over the same square foot area of the silt lake bed will be a fraction of a second when traveling. One second is used as a conservative estimate.



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$$\tau = 0.5\rho_w C_{fs} V_{prop}^2$$

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Where A and n are erosion parameters from SedFlume testing

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Parameters			Units	Notes
Water density	ρ	999.7	kg/m3	freshwater at 4 deg C
Clearance distance Propeller shaft to lakebed	C	0.61	m	
Propeller Diameter	Dp	0.3	m	Maximum expected prop size
Acceleration due to gravity	g	9.81	m/s2	
Efflux velocity from prop	Uo	10.27	m/s	Prop velocity calculated using USEPA 1998
Maximum bottom velocity	Vb	0.94	m/s	Prop velocity at bottom calculated using USEPA 1998
Calculations				
Local skin friction coefficient	$C_{f,p}$	0.0042	-	bottom friction factor for propeller wash
Peak shear stress	τ_{peak}	1.85	N/m2	
Critical bed stress	τ_{cr}	0.0378	N/m2	From standard values for fine silt. Range is 0.0378 to 0.0630 N/m2
Erosion Parameter n	n	3.2	-	From Lower Duwamish AECOM 2012 report

Calculation Table

C (ft)	Vb (m/s)	τ_{peak} (N/m2)	Erosion Rate (cm/s)	Max time (s)	Total Erosion (cm)	
2.00	0.94	1.8	25.32	0.125	3.2	
2.10	0.89	1.7	18.31	0.125	2.3	
2.18	0.86	1.6	14.63	0.125	1.8	
2.24	0.84	1.5	12.30	0.125	1.5	
2.29	0.82	1.4	10.66	0.125	1.3	
2.33	0.81	1.4	9.45	0.125	1.2	
2.37	0.79	1.3	8.50	0.125	1.1	
2.41	0.78	1.3	7.74	0.125	1.0	
				1	**13.4**	cm
					5.3	inches

The table increases the depth below the prop (C) by incrementing in the amount that has been eroded. Bottom shear stress and bottom velocity is calculated for the new depth and a new erosion rate.

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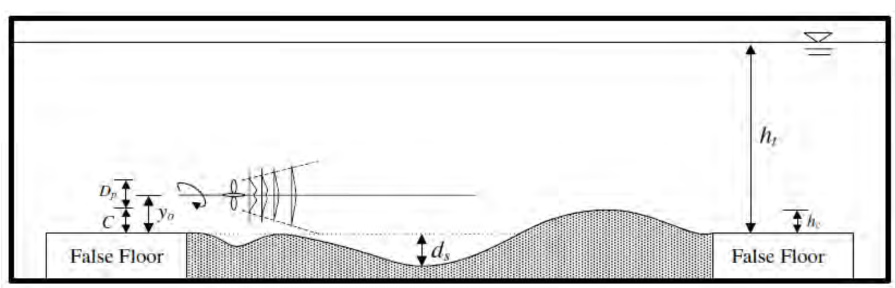

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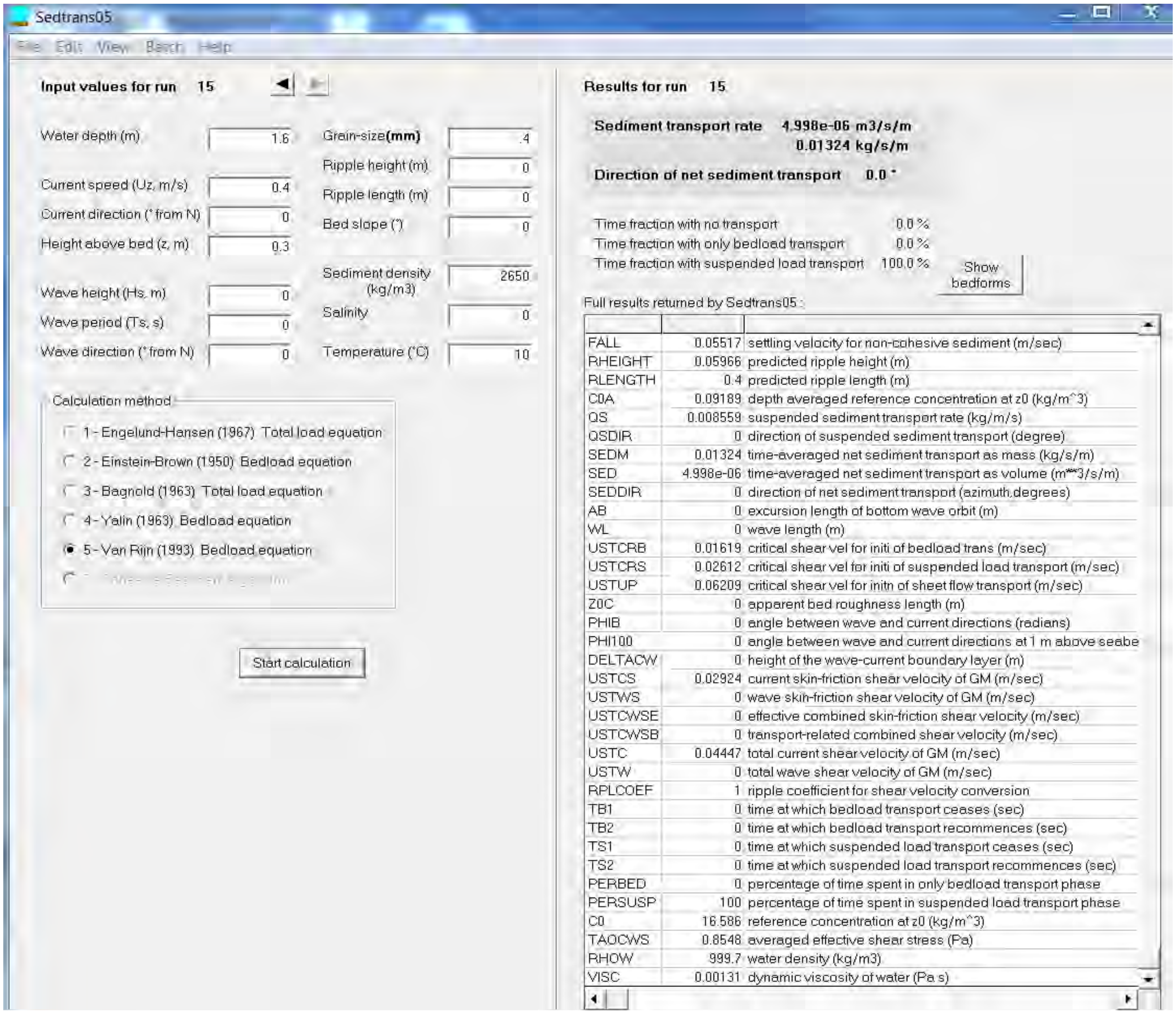
Sedtrans05
File Edit View Batch Help
Input values for run 15
Water depth (m) 1.6
Current speed (Uz, m/s) 0.4
Current direction (° from N) 0
Height above bed (z, m) 0.3
Wave height (Hs, m) 0
Wave period (Ts, s) 0
Wave direction (° from N) 0
Grain-size (mm) .4
Ripple height (m) 0
Ripple length (m) 0
Bed slope (°) 0
Sediment density (kg/m3) 2650
Salinity 0
Temperature (°C) 10
Calculation method
1 - Engelund-Hansen (1967) Total load equation
2 - Einstein-Brown (1950) Bedload equation
3 - Bagnold (1963) Total load equation
4 - Yalin (1963) Bedload equation
5 - Van Rijn (1993) Bedload equation
Start calculation
Results for run 15
Sediment transport rate 4.998e-06 m3/s/m
0.01324 kg/s/m
Direction of net sediment transport 0.0 °
Time fraction with no transport 0.0 %
Time fraction with only bedload transport 0.0 %
Time fraction with suspended load transport 100.0 %
Show bedforms
Full results returned by Sedtrans05 :
FALL 0.05517 settling velocity for non-cohesive sediment (m/sec)
RHEIGHT 0.05966 predicted ripple height (m)
RLENGTH 0.4 predicted ripple length (m)
C0A 0.09189 depth averaged reference concentration at z0 (kg/m^3)
QS 0.008559 suspended sediment transport rate (kg/m/s)
QSDIR 0 direction of suspended sediment transport (degree)
SEDM 0.01324 time-averaged net sediment transport as mass (kg/s/m)
SED 4.998e-06 time-averaged net sediment transport as volume (m**3/s/m)
SEDDIR 0 direction of net sediment transport (azimuth,degrees)
AB 0 excursion length of bottom wave orbit (m)
WL 0 wave length (m)
USTCRB 0.01619 critical shear vel for initi of bedload trans (m/sec)
USTCRS 0.02612 critical shear vel for initi of suspended load transport (m/sec)
USTUP 0.06209 critical shear vel for initn of sheet flow transport (m/sec)
Z0C 0 apparent bed roughness length (m)
PHIB 0 angle between wave and current directions (radians)
PHI100 0 angle between wave and current directions at 1 m above seabe
DELTACW 0 height of the wave-current boundary layer (m)
USTCS 0.02924 current skin-friction shear velocity of GM (m/sec)
USTWS 0 wave skin-friction shear velocity of GM (m/sec)
USTCWSE 0 effective combined skin-friction shear velocity (m/sec)
USTCWSB 0 transport-related combined shear velocity (m/sec)
USTC 0.04447 total current shear velocity of GM (m/sec)
USTW 0 total wave shear velocity of GM (m/sec)
RPLCOEF 1 ripple coefficient for shear velocity conversion
TB1 0 time at which bedload transport ceases (sec)
TB2 0 time at which bedload transport recommences (sec)
TS1 0 time at which suspended load transport ceases (sec)
TS2 0 time at which suspended load transport recommences (sec)
PERBED 0 percentage of time spent in only bedload transport phase
PERSUSP 100 percentage of time spent in suspended load transport phase
C0 16.586 reference concentration at z0 (kg/m^3)
TAOCWS 0.8548 averaged effective shear stress (Pa)
RHOW 999.7 water density (kg/m3)
VISC 0.00131 dynamic viscosity of water (Pa s)